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KEITHLEY

Model 181
Operator's Manual

Contains Operating Instructions for the Model 181 Digital Nanovoltmeter

Publications Date: February 1982
Document Number: 32421 Rev. A

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Operator's Manual
Model 181
Digital Nanovoltmeter

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Document Number 32421

SPECIFICATIONS

DC VOLTS RANGE	5½-DIGIT RESOLUTION	ACCURACY ±(%rdg + digits) 24 HR., 22°-24°C	ACCURACY ±(%rdg + digits) 1 YR., 18°-28°C	TEMPERATURE COEFFICIENT ±(%rdg + digits)/°C 0°-18°C & 28°-35°C	INPUT RESISTANCE	MAXIMUM ALLOWABLE INPUT	NMRR (LINE FREQUENCY)
2mV	10 nV	0.006% + 5 d*	0.015% + 5d*	0.002 % + 3 d	> 1GΩ	120V**	> 90dB
20mV	100 nV	0.006% + 2 d*	0.015% + 2d*	0.002 % + 0.5d	> 1GΩ	120V**	> 80dB
200mV	1 μV	0.006% + 2 d	0.015% + 2d	0.002 % + 0.2d	> 1GΩ	120V**	> 80dB
2 V	10 μV	0.004% + 1.5d	0.007% + 2d	0.0007% + 0.2d	> 1GΩ	1000V	> 60dB
20 V	100 μV	0.004% + 1.5d	0.01 % + 2d	0.0008% + 0.2d	10MΩ	1000V	> 60dB
200 V	1mV	0.004% + 1.5d	0.01 % + 2d	0.0008% + 0.2d	10MΩ	1000V	> 60dB
1000 V	10mV	0.005% + 1.5d	0.01 % + 2d	0.0012% + 0.2d	10MΩ	1000V	> 60dB

CMRR: 160dB on mV ranges, 140dB on V ranges; at DC and line frequency (50 or 60Hz). (1kΩ unbalance)

*When properly zeroed.
**10 seconds maximum; 35V rms continuous.

IEEE-488 BUS IMPLEMENTATION:

Multiline Commands: DCL, LLO, SDC, GET.
Uniline Commands: IFC, REN, EOI, SRQ, ATN.

PROGRAMMABLE PARAMETERS:
Front Panel Controls: Range, Filter, Zero, Damping, Hi Resolution.
Internal Parameters: SRQ Response, Trigger Modes, Data Terminators.

ADDRESS MODES: Talk-Only and Addressable.

TRIGGER MODES:
One Shot: Updates output buffer once at first valid conversion after trigger on TALK and/or GET.
Continuous: Updates output buffer at all valid conversions after trigger.

GENERAL

NOISE: Less than 30nV p-p on lowest range with Filter on.

INPUT CAPACITANCE: 5000pF on mV ranges.

SETTLING TIME: 0.5s to within 25 digits of final reading with Filter on, Damping off.

FILTER: 3-pole digital; RC = 0.5, 1 or 2 seconds depending on range.

CONVERSION SPEED: 4 readings/second.

DISPLAY: Seven 13mm (0.5 in.) LED digits with appropriate decimal point and polarity.

OVERLOAD INDICATION: Display indicates polarity and OFLO.

ANALOG OUTPUT:
Accuracy: ±(0.15% of displayed reading + 1mV).
Time Constant: 400ms.
Level: ±2V full scale on all ranges; X1 or X1000 gain.

ISOLATION: Input LO to Output LO or power line ground: 1400V peak, 5 × 10^5V•Hz, greater than 10^9Ω paralleled by 1500pF

WARMUP: 1 hour to rated accuracy when properly zeroed.

ENVIRONMENTAL LIMITS: **Operating**: 0°C to 35°C, 0% to 80% relative humidity. **Storage**: −25°C to 65°C.

POWER: 105-125V or 210-250V (internal switch selected), 50-60Hz, 30V•A maximum.

INPUT CONNECTORS: Special low thermal for 200mV and lower ranges. Binding posts for 2V to 1000V ranges.

DIMENSIONS, WEIGHT: 127mm high × 216mm wide × 359mm deep (5" × 8½" × 14⅛"). Net weight 3.85kg (8½ lbs.).

ACCESSORY SUPPLIED: Model 1506 Low Thermal Input Cable.

ACCESSORIES AVAILABLE:
Model 1019 Rack Mounting Kit
Model 1483 Low Thermal Connection Kit
Model 1484 Refill Kit for 1483 Kit
Model 1485 Female Low Thermal Input Connector
Model 1486 Male Low Thermal Input Connector
Model 1488 Low Thermal Shorting Plug
Model 1503 Low Thermal Solder and Flux
Model 1506 Low Thermal Input Cable (4 ft., Clips)
Model 1507 Low Thermal Input Cable (4 ft., Lugs)
Model 1815 Maintenance Kit

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SECTION 1
GENERAL INFORMATION

1.1 INTRODUCTION

The Keithley Model 181 is a highly sensitive nanovoltmeter with a large, easy to read 5½ or 6½ digit display. The Model 181 is unique in that it combines microprocessor technology with a new concept in low-noise, high-gain front ends, resulting in a programmable instrument with sensitivity down to 10nV. The Model 181 provides highly accurate, stable, low-noise readings on seven ranges for DC voltage measurements between 10nV and 1000V. The mV ranges use a special low-thermal input connector, while connections for the higher voltage ranges are made through two 5-way binding posts. Additional versatility is afforded by the inclusion of an IEEE-488 interface which allows the unit to communicate with other instrumentation.

1.2 MODEL 181 FEATURES

The Model 181 includes the following features:

- High Sensitivity. The resolution of the Model 181 on the 2mV range is 10^{-8} volts (10nV).
- 5½ or 6½ Digit Resolution. Normal 5½ digit display resolution may be increased to 6½ digits at the touch of a button.
- IEEE-488 Interface. A built in IEEE-488 interface allows the instrument to communicate with other devices such as a central controller or printer.
- Analog Output. An analog output, which accurately reflects the displayed readings, is available from the rear panel.
- 3-pole Digital Filter. The internal 3-pole filter minimizes the effects of noise in voltage readings and may be controlled from the front panel or IEEE bus.
- Separate Inputs. A special input connector is used for the mV ranges to minimize thermal emf generation.
- Isolated Low Terminals. The low signal connections for both inputs are isolated from power line ground and from IEEE low to minimize ground loop problems.
- Color Coded Front Panel. Inputs, range switches, and other front panel controls are marked to form color-coded groups for easier operation.

1.3 OPTIONAL ACCESSORIES

A summary of the many optional Model 181 accessories is listed in the following paragraphs. These accessories are designed to enhance the capabilities of the instrument and are described in more detail in the Model 181 Service Manual, Document Number 30816. Contact the nearest Keithley representative or the factory to obtain accessories.

1. Model 1483 Low-Thermal Connection Kit. The Model 1483 kit contains a crimp tool, pure copper lugs, low-thermal cadmium solder, copper alligator clips, and assorted hardware. It may be used for constructing experimental circuits with low-thermal connections to minimize thermal emf effects.
2. Model 1484 Refill Kit. The Model 1484 kit contains replacement parts for the Model 1483.
3. Model 1485 Low-Thermal Female Connector. The Model 1485 connector is used for the mV INPUT on the front panel of the Model 181.
4. Model 1486 Low-Thermal Male Connector. The Model 1486 connector mates with the Model 1485 female connector. It can be used to construct custom cables of various lengths. This connector is used with the Model 1506 and 1507.
5. Model 1488 Low-Thermal Shorting Plug. The Model 1488 provides a means of shorting the mV INPUT to check instrument offset and drift.
6. Model 1503 Low-Thermal Solder. The Model 1503 kit contains low-thermal cadmium solder to make solder connections for low voltage measurements.
7. Model 1506 Low-Thermal Input Cable. The Model 1506 cable is supplied with the unit. It is a specially designed, four foot triaxial cable that provides excellent shielding for sensitive measurements. The Model 1506 has two color coded alligator clips on one end, and a Model 1486 low-thermal male connector at the other end.
8. Model 1507 Low-Thermal Cable. The Model 1507 cable is similar to the Model 1506, except that the alligator clips are replaced by spade lugs. The Model 1507 is constructed of a four foot triaxial cable and has a Model 1486 low-thermal male connector on one end.
9. Model 1815 Maintenance Kit. The Model 1815 kit contains a calibration cover and extender cables that are helpful when making service adjustments to the Model 181. The calibration cover replaces the top cover while making these adjustments. The extender cables allow individual PC cards to be partially removed from the unit during maintenance.
10. Model 1019 Rack Mounting Kit. The Model 1019 kit allows the Model 181 to be conveniently mounted in a standard 19 inch rack.

1.4 WARRANTY INFORMATION

Warranty information may be found inside the front cover of this manual. If warranty service is required, contact the Keithley representative in your area or the factory to determine the correct course of action. Keithley maintains service

facilities in the United States, West Germany, Great Britain, France, the Netherlands, Switzerland and Austria. Information concerning the application, operation or service of your instrument may be directed to the applications engineer at any of the previously mentioned locations. Check inside front cover of this manual for addresses.

1.5 MANUAL ADDENDA

Because of a policy of constant improvement, it may become necessary to make changes to the unit. Any modifications will be listed in an addendum attached to the inside back cover of this manual. Be sure to note these changes before attempting to operate the instrument.

1.6 SAFETY SYMBOLS AND TERMS

Safety symbols used in this manual are as follows:

The symbol ⚠ on the instrument denotes that the user should refer to the operating instructions.

The symbol ↯ on the instrument denotes that 1000V or more may be present on the terminal(s).

The **WARNING** used in this manual explains dangers that could result in personal injury or death.

The **CAUTION** used in this manual explains hazards that could damage the instrument.

1.7 SCOPE OF OPERATOR'S MANUAL

This manual is intended to familiarize the operator with the operating controls and features of the Model 181 nanovoltometer. Some of the items covered in this manual include: basic and nanovolt measurement techniques, possible problems that could result when making measurements, additional Model 181 uses, operation of the Model 181 on the IEEE-488 bus, and programming examples. For technical information including performance verification, theory of operation, and maintenance procedures, refer to the Model 181 Service Manual.

1.8 SPECIFICATIONS

For Model 181 detailed specifications, refer to the specifications that precede this section.

Figure 1-1. Model 181 Front Panel View

SECTION 2
OPERATION

2.1 INTRODUCTION

This section contains information needed for basic Model 181 operation. Be sure to read this entire section before attempting to operate the unit.

2.2 UNPACKING AND INSPECTION

The Model 181 was carefully inspected before shipment. Upon receiving the unit, unpack all the items from the shipping carton and check for any damage that might have occurred during shipment. Report any damage to the shipping agent at once. Save the original packing material for possible future reshipment. Contact your nearest Keithley representative or the factory if the unit fails to function properly.

The following items are included with every Model 181 shipment:

1. Model 181 Nanovoltmeter
2. Model 181 Operator's Manual
3. Model 181 Service Manual
4. Model 1506 Low-Thermal Input Cable
5. List of computer programs.
6. Additional accessories as ordered.

2.3 PREPARING FOR OPERATION

Before operating the Model 181, the appropriate line voltage must be selected and the unit must be plugged into a proper power source. This section covers each of these steps; be sure to observe any precautions that are given.

1. Line Voltage Selection. The operating voltage of the Model 181 was set at the factory as indicated on the rear panel. Do not attempt to operate the unit with power line voltages outside the indicated range. If it is necessary to change the operating voltage, the top cover of the instrument must be removed to allow access to the line voltage selection switch.

WARNING

These instructions are intended for use only by qualified service personnel. Do not remove the top cover unless qualified to do so because of the possibility of electric shock.

NOTE

The Model 181 is designed to operate with 105-125V or 210-250V as selected by the internal switch. For operation on 90-110V and 180-220V power sources, a special power transformer must be installed. Contact your Keithley representative or the factory for information.

To remove the top cover, remove the two screws securing the cover to the rear panel. Then lift off the cover from the back until the tabs at the front of the cover clear the front panel. Then remove the cover entirely.

Refer to Figure 2-1 for the location of the voltage switch. Set the switch to the appropriate voltage. Also make sure the proper fuse is installed; refer to Table 2-1 for the proper type.

Replace the top cover in the reverse order. Make sure the tabs at the front of the cover mate with the slots in the front panel. Finally, install the two screws that secure the top cover to the rear panel.

Table 2-1. Fuse Selection

Input Voltage	Fuse Type	Fuse Keithley P/N
115VAC	3AG, SLO BLO 250V, 1/4A	FU-17
230VAC	3AG, SLO BLO 250V, 1/8A	FU-20

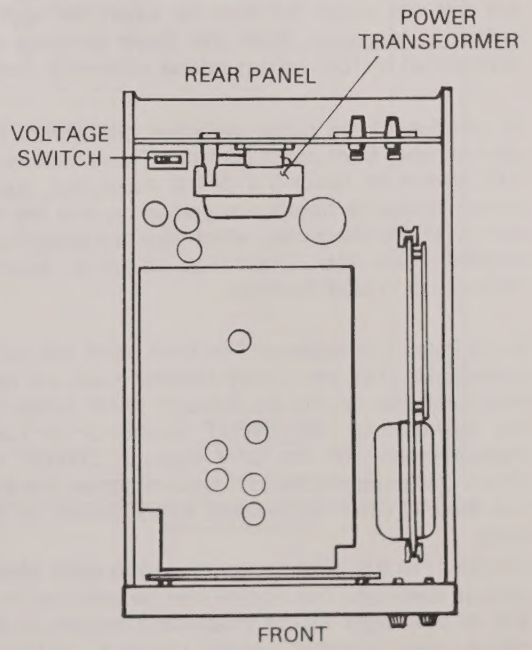


Figure 2-1. Line Voltage Switch Location

2. Power Line Connection. The Model 181 power cord is supplied with a 3-prong plug that is designed to be used with grounded outlets. Connect the female end of this cord to the power receptacle on the rear panel of the unit. Connect the other end to an appropriate power source.

CAUTION

Make sure the proper line voltage is selected as described in the last section. Failure to do so may result in damage to the instrument, possibly voiding the warranty.

3. Power-up Procedure. Once the power connections have been made, the unit may be turned on by depressing the front panel power switch. The Model 181 display should show the line frequency and software revision level (e.g. F60 b7) for approximately one second. After that, the unit will revert to the normal display mode. In addition, the 1000V range indicator light should be on. This is one of the power-on default conditions that are explained more fully in paragraph 4.5.

2.4 OPERATING CONTROLS AND CONNECTIONS

1. Front Panel Controls. The front panel controls are shown in Figure 2-2. In addition to the power switch previously described, the Model 181 has a number of other front panel switches. The 2mV, 20mV, and 200mV switches are used to select one of the mV measurement ranges. The 2V, 20V, 200V, and 1000V switches are used to select one of the normal voltage ranges. The light above the selected range will turn on when the appropriate switch is depressed. Note that these switches may be superseded by IEEE commands as outlined in Section 4.

   In addition to the range switches, the Model 181 has several other front panel controls. These include: the HI RES switch to select 5½ or 6½ resolution, the ZERO switch to enable baseline suppression, and the FILTER and DAMPING switches, which alter the response of the internal 3-pole filter. These features will be described in more detail in later sections.

2. Front Panel Connections. The front panel has two input connectors. The two 5-way binding posts are used for measurements on the 2V through 1000V ranges, while the low-thermal mV INPUT connector is used for measurements on the 2mV through 200mV ranges. When using the mV INPUT, be sure to use the supplied low-thermal cable to minimize errors caused by thermal emfs.
3. Display. The 6½ digit display is used to make Model 181 voltage readings. The display may be switched to either 5½ or 6½ digits at the touch of a button. A leading minus sign appears when negative voltages are measured, and the decimal point is automatically placed. Overrange is indicated by an "OFLO" message.
4. IEEE Status Lights. The TALK, LISTEN, and REMOTE indicator lights show the present IEEE status of the Model 181. For complete IEEE information, refer to Section 4.
5. Rear Panel Controls and Connections. The rear panel controls and connections are shown in Figure 2-3. An analog output is available through the two 5-way binding posts. The switches and connector shown in the lower left corner are for use with the IEEE-488 bus. The functions and operation of these connectors and switches will be covered in more detail in later paragraphs.
6. Tilt Bail. The tilt bail is useful for elevating the front panel of the instrument to a convenient height. To extend the tilt bail, rotate it 90° away from the bottom cover; then push the bail upward until it locks into place. To retract the bail, first pull the bail down away from the front cover to release the locking mechanism; then rotate the bail until it is flush with the bottom cover.

2.5 BASIC VOLTAGE MEASUREMENT

Normal voltage measurements are made on the 2V through 1000V ranges. To use one of these ranges, the source to be measured must be connected to the V INPUT. The following paragraphs describe the basic procedure for making these voltage measurements.

1. Turn on the Model 181 by depressing the front panel power switch. As previously described, the unit should momentarily display the line frequency and software revision level. Allow a one hour warm-up period to obtain rated accuracy. Four hours are required for minimum drift.
2. Select the desired voltage range by depressing the appropriate range button. Select a range that can easily handle the maximum voltage to be measured.
3. Select other front panel operating modes, such as HI RES, ZERO, DAMPING,and FILTER, as required. Refer to paragraph 2.8 for further information on these controls.
4. Connect the source to be measured to the V INPUT terminals as shown in Figure 2-4. Note that circuit ground is normally connected to the LO terminal, while the HI terminal should be connected to the point to be measured.

CAUTION

Do not exceed 1000V between the HI and LO V INPUT terminals or the instrument might be damaged. Note that the LO INPUT terminal floats and is not connected to power line ground. Therefore, it is important that the potential between the LO input terminal and power line ground not exceed 1400V, or the instrument might be damaged.

WARNING

Observe normal safety precautions when connecting the Model 181 to potentially lethal voltage sources. Failure to observe these precautions may result in serious personal injury because of electric shock.

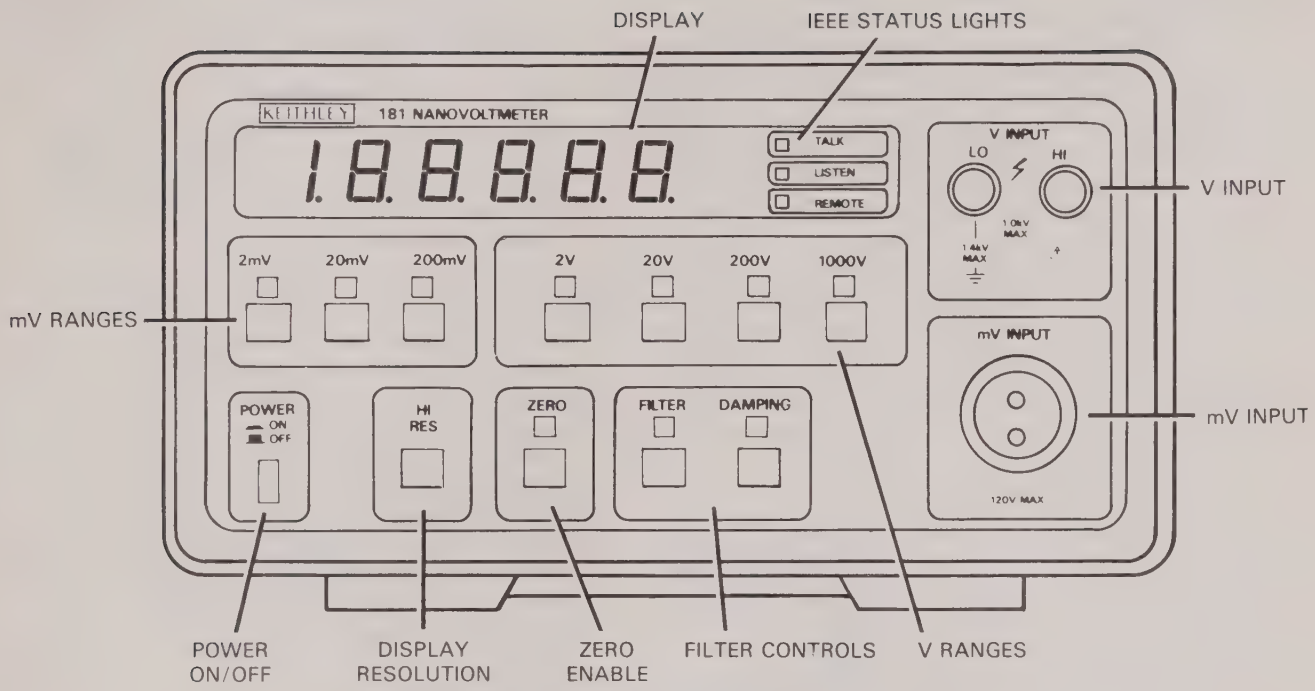


Figure 2-2. Front Panel Controls and Connections

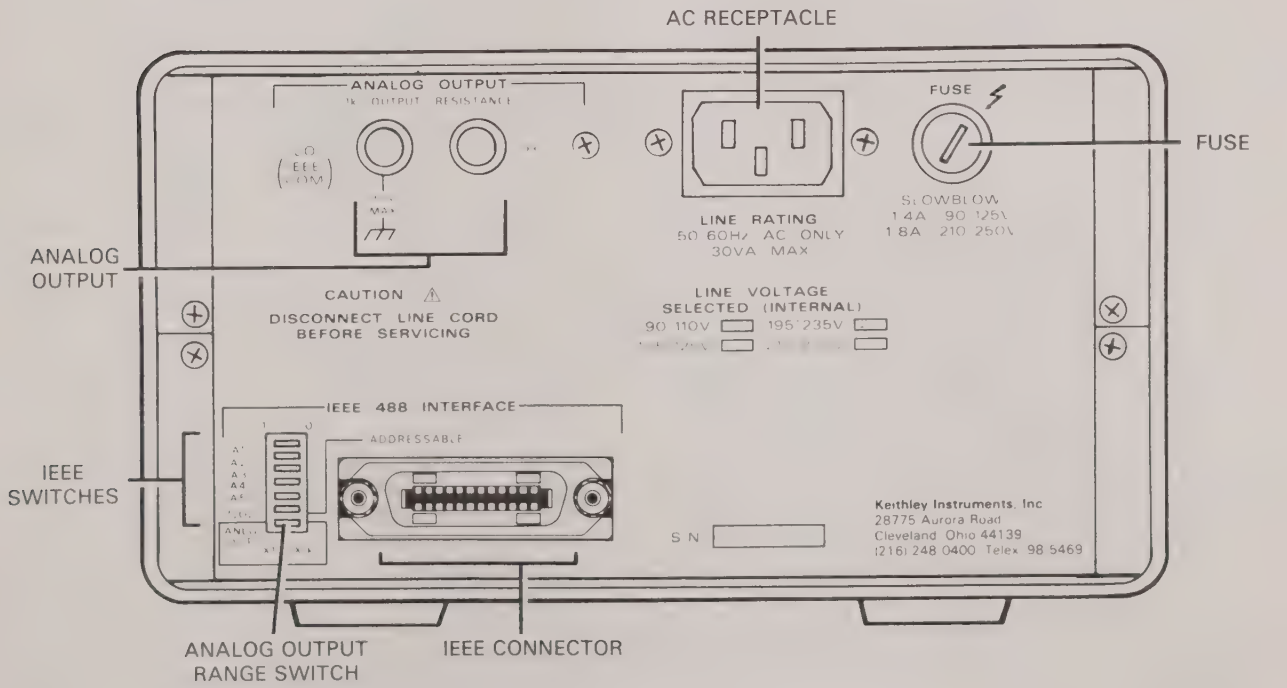


Figure 2-3. Rear Panel Controls and Connections

5. Observe the display; if an "OFLO" is shown, switch to the next higher range. Use the lowest range possible to make the measurement. This procedure will achieve the best resolution.
6. Make the voltage reading. The display shows the reading directly in DC volts with a leading minus sign for negative voltages. No conversion is necessary as the decimal point is automatically placed on all ranges.

7. The Model 181 input impedance is greater than $10^9\Omega$ on the 2V range and equal to 10MΩ on the 20V through 1000V ranges. Thus, loading should not be a problem except with very high source resistance values. Refer to paragraph 2.10 for precautions to be taken under those conditions.

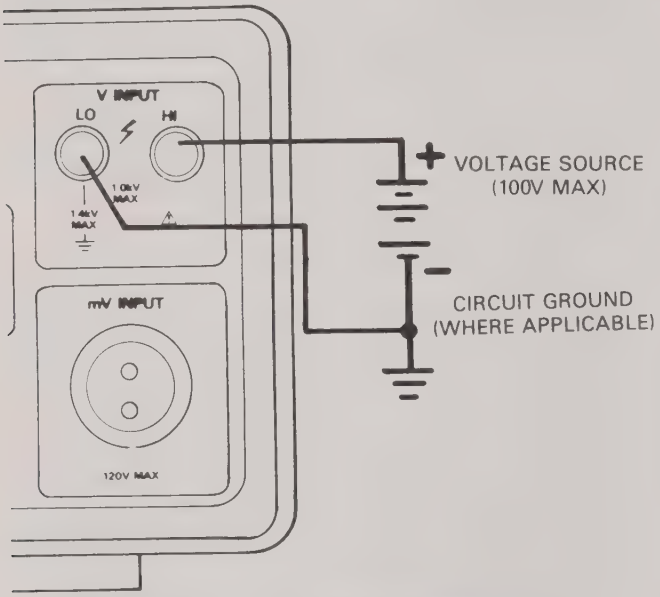


Figure 2-4. Basic Voltage Measurements

2.6 NANOVOLT AND MICROVOLT MEASUREMENTS

The Model 181 may be used to make very low voltage readings down to a resolution of 10nV. These readings are made on one of the mV ranges by using the mV INPUT on the front panel.

The following paragraphs describe the basic procedure for making these measurements.

1. Turn on the Model 181 with the front panel POWER switch. Allow the unit to warm-up for at least an hour for rated accuracy. To guarantee low drift, allow at least four hours.
2. Select the desired mV range with the appropriate front panel switch. Use a range appropriate for the voltage to be measured.
3. Select other parameters such as HI RES, DAMPING, FILTER, and ZERO as needed. Refer to paragraph 2.8 for more details on these controls.
4. Connect the low-thermal cable to the mV input. Connect the alligator clips of the cable to the voltage source to be measured as shown in Figure 2-5.

CAUTION

Do not exceed 120V momentary, 35V continous, between the mV INPUT terminals, or 1400V between the mV low terminal and ground. Failure to observe these precautions may result in damage to the unit.

5. Observe the display reading; if the unit is in overflow, select the next higher range. If an overflow condition exists on the 200mV range, use the V INPUT and appropriate range as outlined in the preceding paragraph.
6. Take the voltage reading. The reading may be made directly, in millivolts, since the decimal point is automatically placed. A leading minus sign will be displayed for negative voltages.
7. Because of the very low signal levels involved, unwanted noise, as described in paragraph 2.11, may upset the accuracy of the measurement.

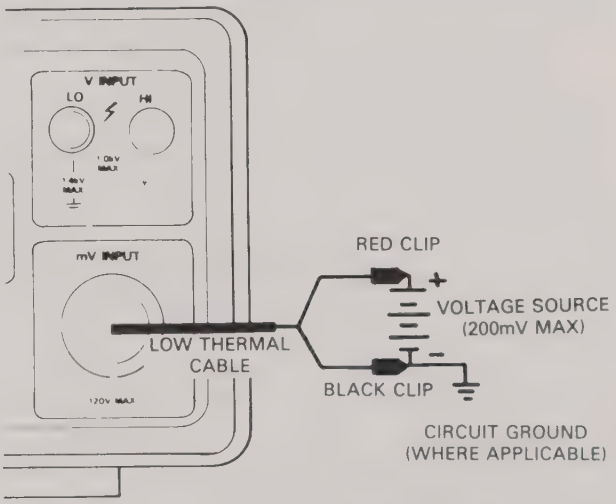


Figure 2-5. mV and nV Measurements

2.7 SPECIAL MEASURING SITUATIONS

Some situations may call for a wide range of voltage measurements that neither the V input nor mV input can handle alone. In those cases, it may be convenient to use a common ground for both the V and mV inputs. Since the LO terminals of the mV and V inputs are internally connected together, it is only necessary to connect the mV Lo terminal (black lead of the Model 1506 low-thermal cable) to common of the circuit under test, as shown in Figure 2-6. Using this method, either the V HI or mV HI terminal can be used as the test probe, depending on the voltage to be measured.

CAUTION

Do not exceed the maximum input limit for the Model 181, especially when the mV HI terminal is connected, or damage to the instrument may occur. Never parallel the mV and V leads to prevent accidental overload to the mV input or inadvertent loading of the circuit under test.

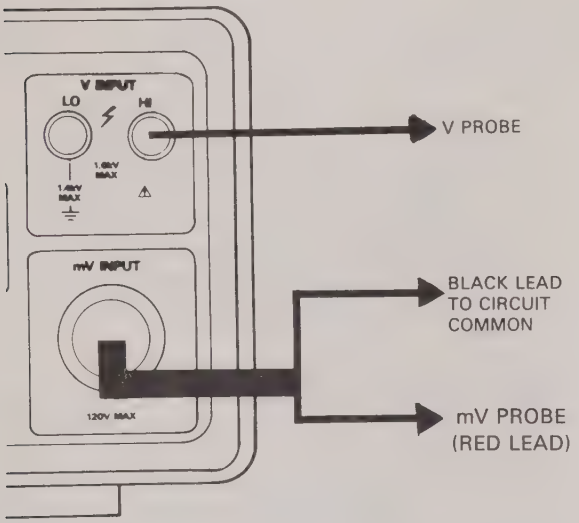


Figure 2-6. Common Ground Connection for V and mV

2.8 ADDITIONAL FRONT PANEL CONTROLS

The Model 181 has additional front panel controls that can be used to enhance the capabilities of the unit. These switches which include HI RES, ZERO, FILTER, and DAMPING, are shown in Figure 2-2. The following paragraphs will describe the operation of these controls in more detail.

HI RES. The display resolution of the Model 181 upon power-up is 5½ digits. The display resolution may be increased to 6½ digits by depressing the HI RES switch. Once the unit is in the 6½ digit mode, the display may be returned to the 5½ digit mode by depressing the HI RES switch a second time. Readings made in the 5½ digit mode have the least significant digit rounded off. HI RES switch affects only the data on the display; data transmitted over the IEEE bus always contains 6½ digit information. For further information on IEEE operation, refer to Section 4.

Zero. The Zero mode serves as a means for baseline suppression. The front panel ZERO indicator light will turn on when the zero mode is enabled. All readings taken with the zero enabled will be the difference between the stored baseline and the actual voltage level.

The baseline is obtained by connecting the instrument to the voltage to be zeroed. For example, if the baseline voltage is 10mV, all subsequent readings will have 10mV subtracted from the actual voltage level.

The zero function is especially useful for nulling out offset voltages, including internal offsets of the Model 181. To use the zero in this manner, short the test leads together with the instrument on the desired range and depress the ZERO switch; the ZERO indicator light should turn on. This stores the residual voltage level as the baseline. All voltage reading taken with zero enabled will then be the actual voltage level since the unwanted voltage will be subtracted from the reading.

Note that baseline suppression for the V and mV ranges operates separately. Switching the unit between a mV and V range, for example, will cancel the ZERO, also causing the front panel ZERO indicator light to turn off.

Controlling the Filter. The Model 181 has an internal 3-pole digital filter that can be controlled by the front panel FILTER and DAMPING controls. Normally, the filter is switched on and off as a function of the rate of change in input signal. Depressing the FILTER button increases the RC time constant of the filter. At the same time, the front panel FILTER light will turn on. The digital filter cannot be totally disabled by the front panel controls. However, it may be disabled by commands given over the IEEE bus. Operating with the filter disabled allows the user to customize Model 181 response by using external filtering. For further information on IEEE commands that control the filter, consult Section 4 of this manual.

The DAMPING button controls whether or not the filter is continuously enabled. When the DAMPING is off, the microprocessor automatically disables the filter when the input voltage changes to permit rapid display update. Once the reading is within 25 digits of the final value on the 2mV range, and within 6 digits on the remaining ranges, the microprocessor then enables the filter to minimize noise in the final reading. When the DAMPING is on, the digital filter is permanently enabled. The unit would normally be operated in this mode only for signals that vary slowly, or with extremely noisy ambient signals.

Through careful use of the FILTER and DAMPING controls, the user can optimize the Model 181 to the required performance, keeping in mind the resulting speed/ noise compromises. Figure 2-7 shows four curves resulting from operating the unit with various combinations of the DAMPING and FILTER controls. Curve A shows the fastest response time because the filter RC time constant is at a minimum. Also, with DAMPING off, the microprocessor initially disables the filter as previously described.

Depressing the FILTER switch as with curve B, has little effect on the response time since the filter is initially off. Curves C and D, on the other hand, show that enabling the DAMPING slows the response down considerably. This can be seen in more detail in Table 2-2, which lists the settling times of the various control combinations.

Table 2-2 Settling Times

Range	Filter Off Damping Off	Filter Off Damping On	Filter On Damping Off	Filter On Damping On
2mV:	4S	16S	8S	32S
20mV:	1S	8S	4S	16S
200mV:	.5S	8S	4S	16S
2V-1000V:	.5S	4S	2S	8S

(The readings all settle to within 0.002% of the Full Range in the specified time.)

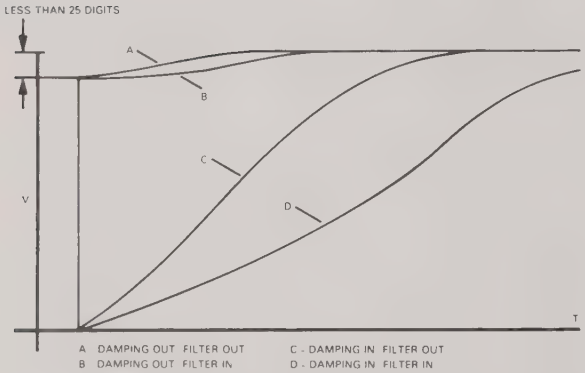


Figure 2-7. Filter Response Graph

2.9 USING THE ANALOG OUTPUT

The analog output of the Model 181 is useful for monitoring the input signal with an external device such as a chart recorder. The analog signal is reconstructed from digital data (supplied by the internal microprocessor) by a 12 bit D/A converter. Because of this configuration, the analog output will accurately reflect the display until an overflow condition is reached. The analog output is optically isolated from the front panel LO terminal to avoid potential ground loop problems. The following paragraphs describe the basic procedure for using the analog output.

1. Connect the measuring device to the two analog output terminals on the rear panel as shown in Figure 2-8.

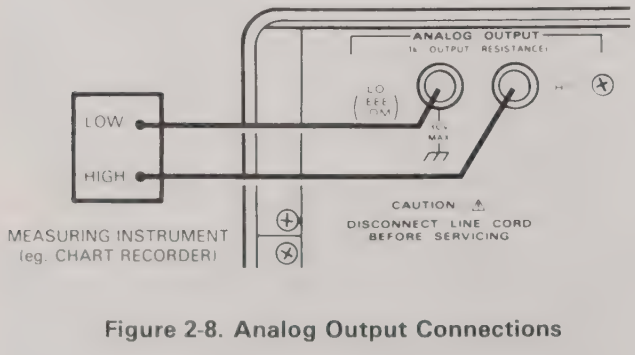


Figure 2-8. Analog Output Connections

CAUTION

The potential between the analog output LO terminal and ground must not exceed 30V. Make sure the external device does not exceed this voltage on its common or ground connections. Failure to observe this precaution may damage the Model 181, possibly voiding the warranty. IEEE common is connected to analog output low.

2. Select the X1 or X1000 range by using the analog output gain switch on the rear panel. This switch is combined with those used to set the IEEE mode in the lower left corner of the rear panel and is clearly marked. (See Figure 2-3.) In the X1 position, the most significant ±2000 counts of the display reading can be covered, while the X1000 position will change the range to cover the least significant ±2000 counts. In this manner, the entire 6½ digits of the display may be represented.
3. If necessary, the analog output may be zeroed with the front panel ZERO control. To do so, depress the ZERO button.

The Model 181 will display an "OFLO" message when the capability of a specific range is exceeded. When this message is displayed, the analog output value will be +2V if the polarity of the input voltage is positive, and -2V if the input voltage polarity is negative.

An analog output range overflow can occur when the Model 181 analog range switch is in the X1000 position. An example of the analog ouput voltage under these conditions is shown in Figure 2-9.* The conditions shown are for the 2mV range, but the output will react similarly on the other voltage ranges if the proper scaling factor is applied. For each tenfold increase in voltage range, the scale of the horizontal axis must also be multiplied by a factor of ten.

The horizontal axis of Figure 2-9 has an input voltage range between -10μV and +10μV. The vertical axis shows an analog output voltage between -2V and +2V, which is the maximum range of the analog output. Beginning at the 0V point on the graph, the analog output follows the input voltage linearly until the input voltage reaches +2μV. The analog output will then suddenly switch to the maximum negative output value of -2V. Thus, for each 4μV increment

* Units with B-7 software.

in input voltage, the output pattern repeats. The action of the analog output for negative input voltages is the same, except that the slope of the graph is negative for these negative-going input voltages.

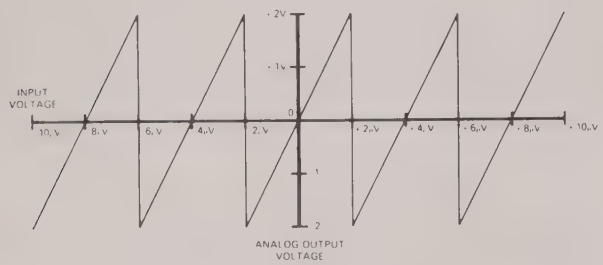


Figure 2-9. X1000 Analog Output

By counting the number of repeating waveforms on a chart recorder, the user can easily determine the actual voltage at the input, even though the range of the analog output was exceeded. If, for example, the +1V point on the second peak with a positive-going slope is noted, it can be clearly determined that the input voltage was +5μV at that particular time.

A summary of analog output information is shown in Table 2-3. Each range of input values corresponds to the increment necessary to cause the output to go through its entire 0 to 2V range. Note that the sensitivity is increased by a factor of a thousand on the X1000 range. For example, when the Model 181 is in the 200mV range, and the analog switch is in the X1 position, the output voltage will swing from 0 to 2V in a smooth manner as the input voltage increases gradually from 0 to 200mV. When the analog output switch is changed to the X1000 position, the input need only swing between 0 and 200μV to obtain the same voltage swing at the analog output. Beyond those input limitations, the output voltage will repeat as shown in Figure 2-9.

The output resistance of the analog ouput is 1kΩ for all voltage ranges regardless of the position of the analog range switch. Thus, loading problems caused by external devices are minimized. To keep loading errors below 1%, the input resistance of any device connected to the analog output should be greater than 100kΩ.

Table 2-3. Analog Output Parameters

	INPUT FOR 0-2V ANALOG OUTPUT	
RANGE	**X1**	**X1000**
2mV	0-2mV	0-2 μV
20mV	0-20mV	0-20 μV
200mV	0-200mV	0-200 μV
2 V	0-2 V	0-2mV
20 V	0-20 V	0-20mV
200 V	0-200 V	0-200mV
1 kV	0-1 kV*	0-1 V*

*1V Full Range Maximum

2.10 SOURCE RESISTANCE CONSIDERATION

The Model 181 has an input resistance greater that 1GΩ (10^9Ω) on the 2mV, 20mV, 200mV, and 2V ranges. The instrument will meet this input resistance specification on the mV ranges even when in overflow with voltages up to 1V. The input resistance on the remaining voltages ranges is 10MΩ. Thus, the Model 181 input resistance is sufficiently high to minimize loading errors in most measuring situations. For voltage sources with very high source resistance, two precautions should be observed when using the Model 181.

Shielding becomes more critical when the source resistance is very high. Otherwise, interference signals may be picked up by the test leads. Noise picked up in this manner can affect the mV ranges more severely, but shielding might be necessary for connections to the V INPUT in extreme situations.

Loading of the voltage source by the Model 181 can become important with high source resistance values. As the source resistance increases, the error due to loading increases. Figure 2-10 shows the method used to determine the percent error due to loading. The voltage source has an internal resistance R_S, while the internal resistance of the Model 181 is represented by R_L. The source voltage is E_S while the voltage actually measured by the meter is E_M.

The voltage actually seen by the meter is attenuated by the voltage-divider action of R_S and R_L and can be found by using the relationship: $E_M = E_S R_L/(R_L + R_S)$.

We can modify this relationship to obtain a formula for percent errors as follows: Percent Error $= 100R_S/(R_L + R_S)$.

From the above, it is obvious that the input resistance of the Model 181 must be at least 99 times greater that the source resistance if the loading error is to be kept to 1%. This maximum 1% error limitation will be achieved on the 2mV through 2V ranges with sources resistances up to 10.1MΩ, while the source resistance should be no greater than 101kΩ if the same 1% error limitation is to be maintained on the 20V through 1000V ranges. If lower errors are required, the source resistance must be correspondingly less.

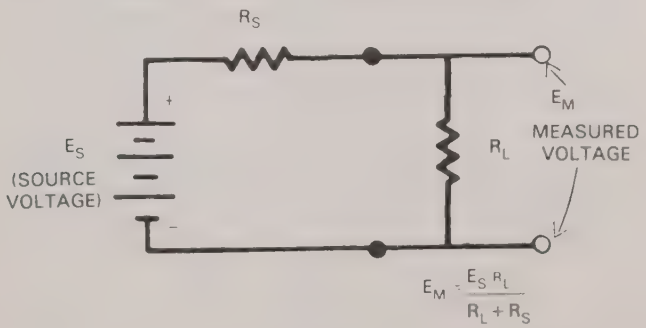


Figure 2-10. Source Resistance Considerations

2.11 MICROVOLT AND NANOVOLT MEASUREMENT CONSIDERATIONS

Low level voltage measurements are subject to various types of noise that can make it difficult to obtain accurate voltage readings. Since the measuring instrument cannot distinguish between signal and noise voltages, the presence of unwanted low level signals can seriously affect a measurement. Some of the phenomena that can cause unwanted noise include: thermocouples (thermoelectric effects), flexing of coaxial cables (triboelectric effects), and the battery action of two terminals (galvanic action). The following paragraphs will discuss potential noise sources in more detail.

Source Resistance Noise. Noise that is present in the source resistance itself is frequently the determining factor in the ultimate resolution of a measurement system. The amount of noise in a given resistance is given by the Johnson Noise Equation as follows:

$$E_{rms} = \sqrt{4KTRF}$$

- F — Noise Bandwidth in Hertz
- R — Source Resistance in Ohms
- T — Temperature °K
- K — Boltzman's Constant (1.38×10^{-23})

At a room temperature of 293°K (20°C), the above can be simplified to read: $E_{rms} = 1.27 \times 10^{-10}\sqrt{RF}$

It has been statistically shown, that p-p noise is approximately five times the rms noise 99% of the time. From this relationship, we can equate the following: $E_{p\text{-}p} = 6.35 \times 10^{-10}\sqrt{RF}$

From the preceding equations it is immediately obvious that the noise voltage can be reduced by lowering the temperature, reducing the resistance, or narrowing the bandwidth. Reducing the resistance is not very useful because the signal voltage will be reduced more than the noise. For example, decreasing the resistance of a current shunt by a factor of 100 will reduce the signal voltage by a factor of 100 as well; the noise, however, will be reduced only by a factor of 10.

Very often, cooling is the only practical method available to reduce the noise. Here again, the reduction available is not as large as it seems because the noise reduction is related to the square root of the change in temperature. For example, to cut the noise voltage in half, the temperature must be decreased from 293°K to 73.25°K, a fourfold decrease.

As an example of determining noise voltage generation, assume that the Model 181 is connected to a voltage source with an internal resistance of 10kΩ. At a room temperature of 20°C (293°K), the p-p noise voltage generated over a bandwidth of 0.5Hz will be:

$$E_{p\text{-}p} = 6.35 \times 10^{-10}\sqrt{(10 \times 10^3)(0.5)}$$
$$E_{p\text{-}p} = 4.5 \times 10^{-8}V = 45nV$$

Thermoelectric potentials. Thermal emf's are small electric potentials generated by differences in the temperature at the junction of two dissimilar metals.

Thermal emf's are particularly troublesome at the low signal levels measured by the mV ranges. To minimize thermal emf drift, use copper leads to connect the circuit to the instrument. The Model 1506 low-thermal cable supplied with the Model 181 is ideal for this purpose. Other suitable low-thermal items are listed in paragraph 1.3 Optional Accessories.

Even with low-thermal cables and connectors, thermal emf's can still be a problem in some cases. It is especially important to keep the two materials forming the junctions at the same temperature. Keeping the two junctions close together is one way to minimize such thermal problems. In some cases, connecting the two junctions together with good thermal contact to a common heat sink may be required.

Most good electrical insulators have good thermal insulation characteristics as well. In cases where such low-thermal conductivity may be a problem, special insulators that combine high electrical insulating properties with high thermal conductivity may be used. Some examples of materials with low electrical conductivity and high thermal conductivity are: hard anodized aluminum, beryllium oxide, specially filled epoxy resin, sapphire, and diamond.

Oxidation of leads and connectors can also lead to thermal emf problems. When copper oxidizes, for example, the resulting copper to copper oxide junction can cause thermal emf's as high as 1000μV/°C. Thus, it is imperative that all connections be kept as clean as possible.

Figure 2-11 shows a representation of how thermal emf's between two dissimilar metals are generated. The test leads are made of the A material, while the B material is the source under test. The temperatures between the junctions are represented by T_1 and T_2. To find the thermal emf for the circuit, the following relationship may be used:

$$E_T = Q_{AB}(T_1 - T_2)$$

- T_1 — Temperature of the A to B junction in °C or °K.
- T_2 — Temperature of the B to A junction in °C or °K.
- Q_{AB} — Thermoelectric coefficient of material A with respect to B, given in μV/°C.

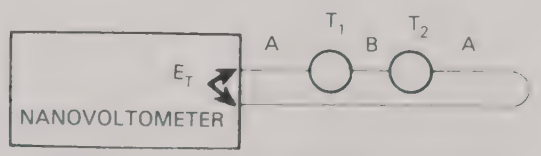


Figure 2-11. Thermal EMF Generation

In the unlikely event the two junction temperatures are identical, the thermal emf's will exactly cancel, since the generated potentials oppose one another. More often, the two junctions temperatures will differ, and considerable thermal emf's will be generated.

A typical test set up might have one or more copper to cadmium-tin junctions. Typically, such a junction has a thermoelectric coefficient of 0.3μV/°C. Since the two materials will frequently have a several-degree temperature differential, it is easy to see how thermal potentials of several microvolts can be generated, even if reasonable precautions are taken.

Magnetic fields. When a conductor cuts through magnetic lines of force, a very small current is generated. This phenomenon will frequently cause unwanted signals to occur in the test leads of a measuring instrument. If the conductor has sufficient length, even weak magnetic fields such as the earth's can create sufficient signals to upset voltage measurements in the nanovolt or millivolt ranges. Thus, several precautions may be taken if magnetic-field induced signals become a problem.

Reducing the length of the leads or minimizing the exposed circuit area are two ways these effects can be minimized. In extreme cases, magnetic shielding may be required. Special metals with high permeability at low flux densities (such as mu metal) are effective in this application.

Even in cases where the conductor is stationary, magnetically induced signals may be a problem. Fields may be produced by various signals such as the AC power line voltage. Large inductors such as power transformers are very good magnetic field generators, so care must be taken to keep the measuring circuit a good distance away from these potential noise sources.

At high current levels, even a single conductor can generate significant fields. These effects can be minimized by using twisted pairs; using this method, the resulting fields will be largely cancelled out.

Ground Loops. When two or more devices are connected together, care must be taken to avoid unwanted signals caused by ground loops. Ground loops usually occur when sensitive instrumentation, such as the Model 181, is connected to other instrumentation with more than one signal return path. One of these return paths may be power line ground. The resulting ground loop causes current to flow through the instrument LO signal leads and then back through the power line ground (See Figure 2-12). Because of this circulating current, a small but undesireable voltage is developed between the LO terminals of the two instruments. This voltage will be added to the source voltage, upsetting the measurement.

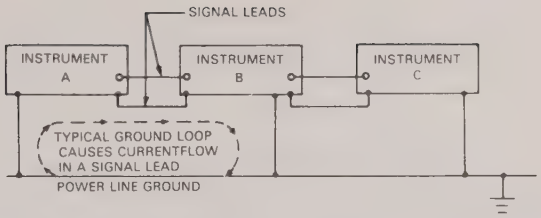


Figure 2-12. Power Line Ground Loops

To see how a ground loop can affect the voltage readings, refer to Figure 2-13. The source to be measured is connected to the nanovoltmeter through the customary HI and LO leads. The resistance of the LO terminal connection is represented by R_1. This resistance is usually very low—about 0.1Ω, but even this low value can be significant if the circulating current is high enough.

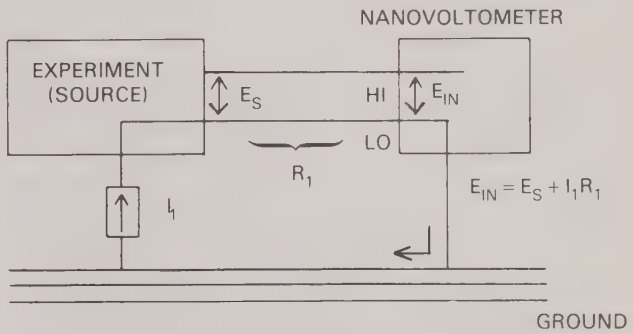


Figure 2-13. Ground Loop Voltage Generation

The source voltage is E_S, while the ground loop current is I_1. The actual voltage seen by the nanovoltmeter is the sum of the source voltage and the IR drop across the LO lead connections, and can be found by using the relationship: $E_{IN} = E_S + I_1R_1$

Thus, for a 100nV source voltage, an R_1 value of 0.1Ω, and a 100nA ground loop current, the total voltage actually seen by the instrument will be 110nV, creating an error of 10%.

Figure 2-14 shows a configuration that will eliminate this type of ground loop problem. Here, only the center instrument is connected to ground. Ground loops are not normally a problem with the Model 181 because the LO input terminals are isolated from power line ground. However, the mV INPUT and V INPUT LO terminals should not be externally connected together as this will create a ground loop. Also, since other instruments may not be designed in the same way, they may cause ground loop problems even though the Model 181 is isolated. When in doubt, consult the manual for other instrumentation in the test setup.

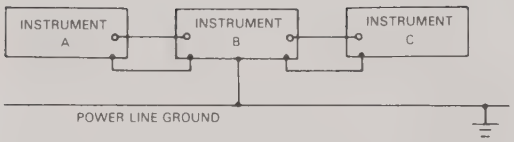


Figure 2-14. Eliminating Ground Loops

RFI. Radio Frequency Interference (RFI) is a general term to describe electromagnetic interference over a wide range of frequencies across the spectrum. RFI can be especially troublesome at the low signal levels measured on the mV ranges, but it may also affect readings on the higher voltage ranges in extreme cases.

RFI can be caused by steady-state sources such as TV or radio broadcast signals, or it can result from impulse sources, as in the case of arcing in high voltage environments. With either type of RFI, the affect on instrument performance can be considerable if enough of the unwanted signal is present.

RFI can be minimized by taking one or more of several precautions when operating the Model 181 in such environments. The most obvious method for minimizing these effects is to keep the instrument as far as possible away from the source. Shielding the instrument, voltage source, and test leads will often reduce RFI to an acceptable level. In extreme cases, a specially constructed screen room may be required to sufficiently attenuate the troublesome signal.

The internal 3-pole filter within the Model 181 may help reduce RFI in some situations. For more serious RFI problems, the user is encouraged to try more effective external shielding.

SECTION 3
APPLICATIONS

3.1 INTRODUCTION

The high sensitivity and very high input impedance of the Model 181 makes it ideal for critical measurements ordinary DVM's are unable to handle. Some of these applications, including standard cell comparison and low resistance measurements, are covered in the following paragraphs.

3.2 STANDARD CELL COMPARISONS

The Model 181 may be used for making standard cell comparisons without the usual problems caused by different ground connections. The input low terminals on the instrument are isolated from ground, eliminating the possibility of shorting out one of the cells when the input connections are reversed.

The greatest concern when making such comparisons is the effect of the measuring instrument on the standard cell voltage. The Model 181 input characteristics minimize these effects because of high input impedance and very low offset current.

The equivalent circuit for making standard cell comparisons is shown in Figure 3-1. V_1 and V_2 represent the two standard cells being compared, and are connected to the HI and LO mV INPUT terminals as shown. The common terminals of the two cells are normally connected to earth ground to prevent electrostatic pickup. Because of the high impedance nature of the measurement, it may be necessary to shield the two standard cells. This shield should also be connected to earth ground as shown in Figure 3-1.

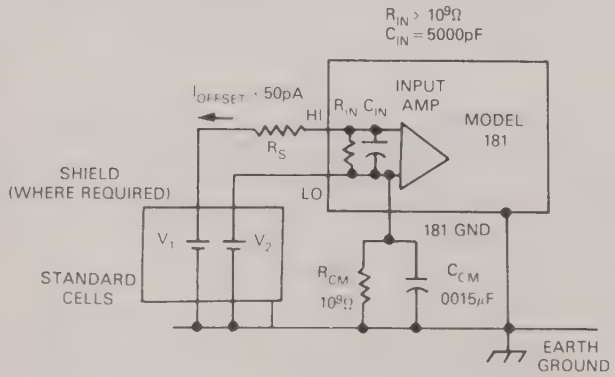


Figure 3-1. Standard Cell Comparison

With this connection, it is assumed that the Model 181 is connected to the power line with the standard 3-prong plug. Since the power line ground is also connected to earth ground, the complete ground connections will be made through the ground wire in the line cord of the instrument.

The amount of current and charge drawn from the cells in Figure 3-1 is determined by the common-mode and normal-mode impedances. The common-mode impedance appears only across V_2 and is represented by the parallel combination of R_{CM} ($> 10^9\Omega$) and C_{CM} ($0.0015\mu F$.) Under typical laboratory conditions (less than 60% relative humidity), the value of R_{CM} is in the $10^{11}\Omega$ to $10^{12}\Omega$ range, and may generally be assumed to be infinite. The capacitance of the Model 1506 low-thermal cable makes up the larger portion of C_{CM}. If the input capacitance should have a detrimental effect on standard cell performance, its value may be essentially balanced out by connecting a 1500pF capacitor between the input HI terminal and earth ground. Since C_{CM} will rarely affect cell performance, this balancing technique is not usually necessary.

The normal-mode impedance is represented by the parallel combination of R_{IN} and C_{IN}. This normal-mode impedance appears between the LO and HI input terminals. The actual amount of charge and current drawn from the two cells depends on the voltage difference between them (V_1-V_2). Typically, the potential difference between V_1 and V_2 is 1mV or less, resulting in a charge of approximately 10^{-12} coulombs that must be supplied by the two cells. In addition, an input offset current of less than 50pA is drawn from the cells under test. Any effects from internal spikes produced by the input multiplexing FET's will be at a minimum, as the spikes will occur at the 4Hz multiplexing rate.

When on the mV ranges, the Model 181 will maintain its high input resistance characteristics ($> 10^9\Omega$) for all voltages up to 1V, even during range changes or when in overload. However, the input impedance drops substantially if the 1V limitation is exceeded. To avoid possible cell degredation under such conditions, it is recommended that a series resistance $1M\Omega$ or greater be connected in series with one of the cells, as shown in Figure 3-1, where R_S is connected between V_1 and the input HI terminal. This safeguard will also protect the cells from degradation in case of improper connections. This resistance, R_S, can be shorted out after an on scale indication is observed, and the reading can then be made in the normal manner.

The basic procedure for making standard cell measurements involves connecting the two cells for comparison to the mV INPUT and setting up the Model 181 as follows:

1. Turn on the power to the Model 181 and allow a one hour warm-up period for the best accuracy. A four hour period is required to minimize drift.
2. Connect the cells to the Model 181 as shown in Figure 3-1. Use the low-thermal cable and mV INPUT on the instrument. Include a $1M\Omega$ resistor for R_S if the cells are to be protected from accidental loading during set-up.

3. Select the appropriate mV range and observe the reading. If the display reading jumps around excessively, enable the damping with the front panel DAMPING switch.
4. Observe the readings; once the display has stabilized, short R_S (if connected), and take the voltage readings.
5. Remove the short from R_S and reverse the lead connections to V_1 and V_2. The LO terminal should now be connected to V_1 and the HI terminal should be connected to V_2. Disable the damping to reduce settling time. Once the reading has stabilized, enable the damping again, if necessary. Once again, short R_S and record the display reading.
6. The standard cell difference may be found by averaging the absolute values of the two readings as follows:

$$\text{Cell Difference} = \frac{|\text{Reading In Step 4}| + |\text{Reading In Step 5}|}{2}$$

This averaging method is necessary to cancel thermal effects, but either reading alone may be sufficiently accurate if precautions to minimize thermal emf generation are observed. The ZERO button may be used to null any residual offset. Also, only copper to copper connections should be used to minimize such thermal effects. As always, the connections should be kept as clean as possible, or the resulting copper to copper oxide junctions may create substantial thermal emf voltage, upsetting the measurement.

The method just described is useful for comparing two standard cell voltages. However, some situations may call for the measurement of a single cell alone. For measuring absolute standard cell voltages, it is best to use the 2V range because the input impedance is greater than $10^9\Omega$.

NOTE

Since the input impedance on the 20V-1000V ranges drops to 10MΩ, those voltage ranges are unsuitable for making absolute standard cell voltage measurements.

Figure 3-2 shows the connections for making absolute standard cell voltage measurements. Once again, R_S is to be left in the circuit until the reading is actually taken. The basic procedure for making the absolute voltage measurement is as follows:

1. Turn on the instrument and allow a one hour warm-up period. Four hours are required to minimize drift.
2. Connect the standard cell to the instrument as shown in Figure 3-2. Be sure to include R_S to protect the cell.
3. Switch the instrument to the 2V range and observe the reading. Be sure the reading is on range.
4. Short out R_S and take voltage reading. Once the reading is complete, remove the short from R_S.

Care should be taken when making absolute readings in this way. If higher voltage ranges are used, the lower input impedance will degrade cell performance. Do not use the mV range for input voltages above 200mV; the input impedance on the mV ranges drops to 1kΩ for inputs greater than 1V.

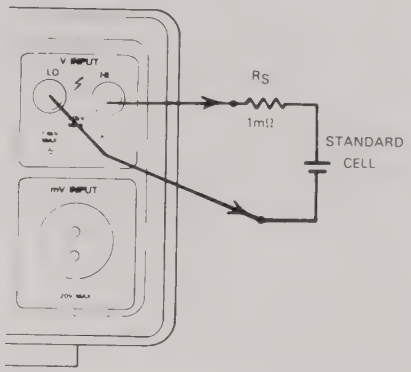


Figure 3-2. Absolute Cell Measurement Connections

3.3 LOW RESISTANCE "LINDECK" MEASUREMENTS

As with the standard cell comparisons, the high resolution of the Model 181 gives the instrument a definite advantage in speed and convenience over potentiometer systems traditionally used to make low resistance measurements.

The method used with the Model 181 places a current source in parallel with the low resistance to be measured, as shown in Figure 3-3. The problem with such measurements has generally been the trade-off between the power level required and the sensitivity of the instrument. In a circuit with a .01Ω resistance, a current source delivering only 10mA will provide a resolution of 0.01% with the Model 181 on the 2mV range. In contrast, a 1μV resolution DVM would require a current of 1A. With the Model 181 measurement, the power level in the resistor will be only 1μW, whereas the measurement made with the DVM would result in a power level of 10mW in a .01Ω resistance.

With this method, the resistance may be found simply by dividing the voltage reading by the current source value. With a 10mA current source and .01Ω resistance, for example, a voltage of 100μV will be developed across the measured resistance.

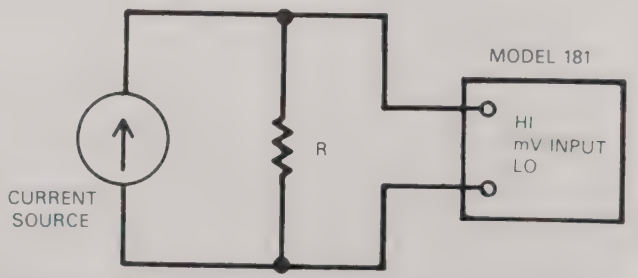


Figure 3-3. Low Resistance Measurement Connections

3.4 TEMPERATURE MEASUREMENTS

The Model 181 may be used with thermocouples or thermopiles to monitor small temperature changes down to a resolution of $\pm 0.001°C$. Connections should be made using appropriate low-thermal materials such as those supplied with the Model 1483 Low-Thermal Connection Kit. Although some shielding is recommended, the high AC rejection of the instrument eliminates most of the problems normally caused nearby AC operated equipment such as heaters, fans, pumps, etc.

The rear panel analog output may be used along with a chart recorder to provide a continuous, permanent record of temperature changes. Alternately, the Model 181 may be connected to the IEEE-488 bus to allow easy transfer of temperature data to a printer or computer. With a suitable controller, the user may take full advantage of Model 181 capabilities, providing full automation of such temperature tests.

3.5 RESISTANCE THERMOMETRY

The Model 181 may be used for resistance thermometry where small deviations are measured with nW power dissipation levels. A stable current source may be used to provide the necessary constant low-level current. A typical resolution, using a 1000Ω germanium thermometer (at 4.2°K) is 0.0002°C, with a power dissipation of only 1nW. (10^{-9}W).

The floating input of the Model 181 eliminates the problems usually encountered when floating four-terminal measurements are made. Note that the Model 181 may be used with a wide range of source resistances, because of the high input impedance of the unit. As with other Model 181 applications, thermometry measurements may be controlled over the IEEE-488 bus.

3.6 SEMICONDUCTOR TESTING

The Model 181 may be used for semiconductor testing on an automated production-line basis. Sensitive measurements can be made on semiconductor devices to determine gain stability, temperature coefficient, etc., without the loading errors associated with many types of equipment. By applying proper programming techniques, a high level of automation through use of the IEEE-488 bus can be achieved.

3.7 JOSEPHSON JUNCTION STUDIES

The Model 181 can be used for Josephson Junction studies, where speed and high sensitivity are a primary requirement. Josephson Junction I-V characteristics can be easily plotted using the Model 181 in conjunction with other instrumentation connected to the IEEE-488 bus. Through the use of an appropriate controller and other instrumentation, virtually complete automation of the necessary instrumentation curve measurements may be obtained.

Josephson Junction measurements are especially vulnerable to the effects of high frequency EMI (Electromagnetic Interference) and RFI (Radio Frequency Interference). Much of this interference may be generated by the microprocessor based instrumentation itself. Still other forms of interference may come from the outside environment. In either case, care must be taken to minimize the coupling of these unwanted signals to the device under test. The almost inevitable high-frequency coupling of unwanted RFI to the Josephson Junction itself will significantly affect the I-V characteristics of the device, rendering the data useless in many cases. The Model 181 has been carefully designed to minimize common-mode RFI that may be coupled through the input cable to the device under test. However, depending on the measuring environment, additional precautions may be required.

Two methods of minimizing RFI effects are shown in Figure 3-4. The device under test is placed within a shielded booth, which is connected to earth ground. Also, a ferrite inductor is placed in series with the HI input lead of the low-thermal cable. This inductor is made up of 4 turns of #28 wire wound around a Keithley CT-7 ferrite core (Fai-rite #2643000701). Note that the inductor is placed just outside the shield, right at the point where the input cable enters the shielded area.

These precautions should eliminate all but the most stubborn RFI problems. In more extreme situations, a second inductor, identical to the first, may be connected in series with the LO input in a similar manner.

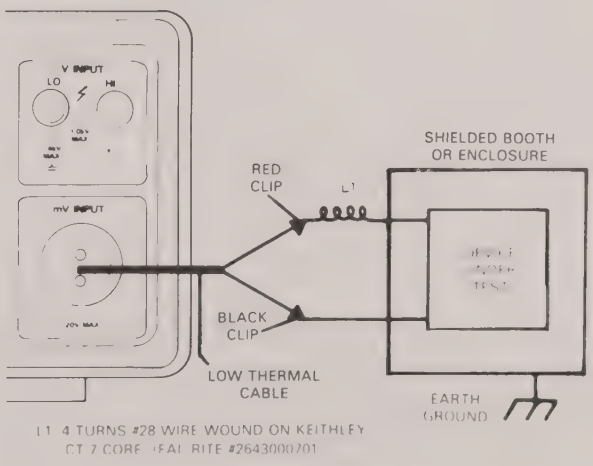


Figure 3-4. Minimizing Josephson Junction RFI Effects

SECTION 4
IEEE OPERATION

4.1 INTRODUCTION TO THE IEEE-488 BUS

The Model 181 has a built in IEEE-488 bus that allows the user to give commands and read data via an external device. All the front panel operating modes except power on-off may be controlled by commands given over the bus.

The Model 181 may be commanded over the bus when the rear panel TO/ADDRESSABLE switch is in the ADDRESSABLE position. When in the TO (talk only) mode, the Model 181 merely outputs data on the bus; no commands may be given when the unit is in this mode. For further information on changing the mode of operation, see paragraph 4.3

A typical bus set-up for controlled operation is shown in Figure 4-1. A typical system will have one controller and several other instruments to which commands are given. Generally, there are three catagories that describe device operation. These catagories are: controller; talker; listener. The controller does what its name implies: it controls the other instruments on the bus. A talker sends data, while a listener receives data. Depending on the type of instrument, any particular device may be a talker only, a listener only, or both a talker and a listener. The Model 181 is capable of being both a talker and a listener, but does not have the capability of being a controller.

Any given system can have only one controller, but any number of talkers or listeners may be present up to the hardware constraints of the bus (see paragraph 4.2). Several devices may be commanded to listen at once, but only one talker can be active at any given time.

Before a device can talk or listen, it must be appropriately addressed. Devices are selected on the basis of their primary address. To avoid confusion, the addressed device is sent a talk or listen command derived from its primary address. The primary address of the Model 181 is set to 5 at the factory, but may be changed at the user's discretion as outlined in paragraph 4.3.

NOTE

Each device on the bus must have a unique primary address. Failure to observe this condition may result in erratic operation.

The IEEE-488 bus is made up of 16 signal lines and 8 ground lines. Eight of these signal lines are used for data, three of the lines control the handshake, and the remaining five lines manage the operation of the bus. The data lines are used for both data and commands. The three handshake lines ensure that all devices properly receive data, while the management lines control the remaining bus functions.

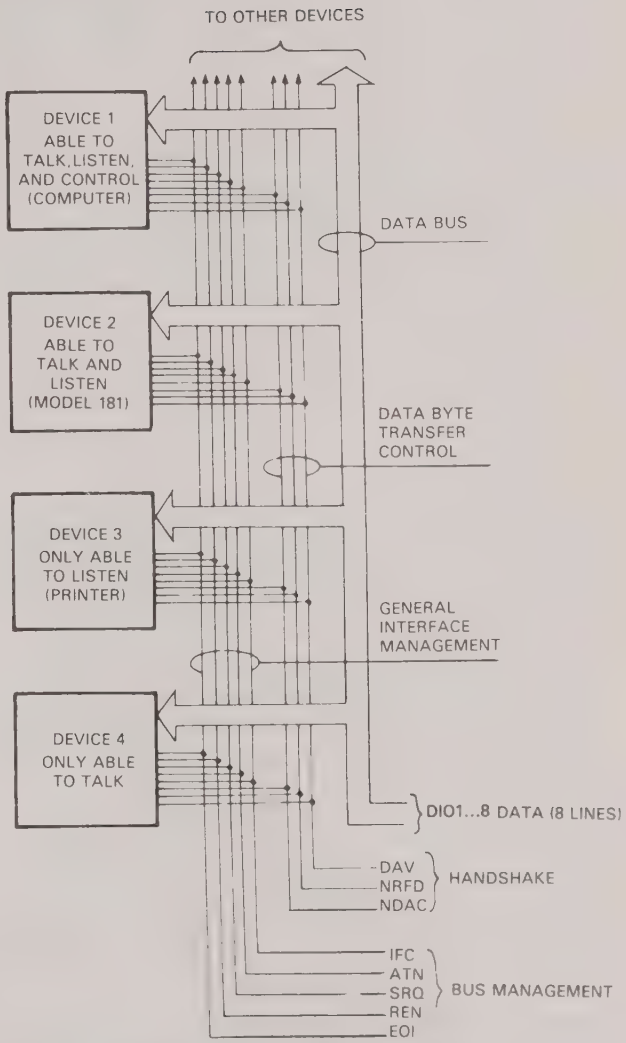


Figure 4-1. IEEE Bus Configuration

4.2 DESCRIPTION OF BUS LINES

The IEEE-488 bus may have up to 15 devices connected at the same time. Each signal line is inverted so that low is true. The following paragraphs briefly describe the purpose of these lines, which are shown in Figure 4-1.

1. Bus Management Lines. These 5 lines are used to control the bus and send certain single line commands. The single-line commands that affect Model 181 operation are explained in more detail in paragraph 4.4.

A. IFC, Interface Clear: Used to send the IFC command to set the bus to a known state.

B. REN, Remote Enable: Used to send the REN command to set up instruments on the bus for remote, operation.

C. EOI, End or Identify: Used to send the END command that usually terminates a multi-byte transfer sequence.

D. SRQ, Service Request: Used by an external device to request service from the controller.

E. ATN, Attention: Used by the controller to indicate whether the data bus contains data or commands.

2. Handshake Lines. The IEEE-488 bus uses three handshake lines that operate in an interlocked sequence. This method ensures reliable data transfer regardless of the transfer rate. Generally, data transfer will occur at a rate determined by the slowest active device on the bus.

   The three handshake lines are: DAV (data valid), NRFD (not ready for data), and NDAC (not data accepted). The device that is the source of the data controls the state of the DAV line, while the NRFD and NDAC lines are controlled by the device accepting data.

   The complete handshake sequence for one byte of data is shown in Figure 4-2. Once the data byte is placed on the data bus, the source checks to see that NRFD is high, and NDAC is low, indicating that all devices on the bus are ready for data. Once this condition is met, the source sets the DAV line low, indicating the data is valid. The NRFD line then goes low; the NDAC line will go high once all the devices have accepted the data. Each device will release the NDAC line at its own rate, but the NDAC line will not go high until the slowest device has accepted the data.

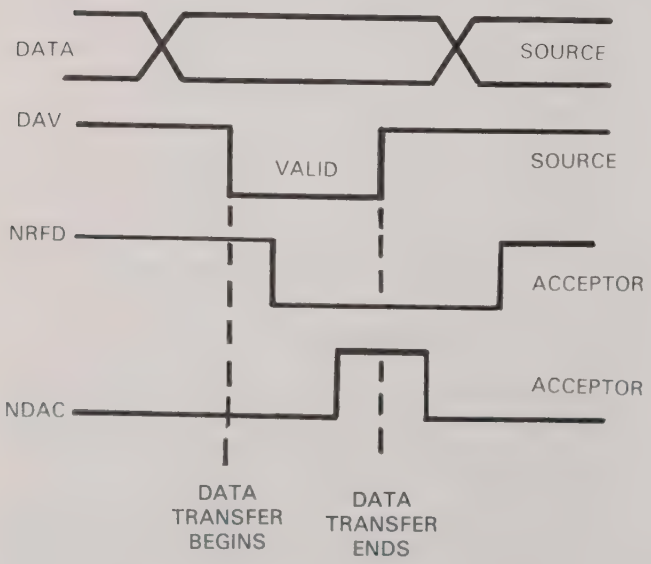


Figure 4-2. IEEE Handshake Sequence

   After the NDAC line goes high, the source then sets the DAV line high, indicating that data is no longer valid. The NDAC line then goes low. Finally, the NRFD line is gradually released by each of the devices at their own rates, until the NRFD line finally goes high when the slowest device is ready, and the bus is set to repeat the sequence with the next data byte.

   The sequence just described is used for both data transfer and the multiline commands. For further information on these commands, refer to paragraph 4.4.

   The IEEE-488-1978 standard uses the terminology just described for the three handshake lines. In some cases, DAC is substituted for NDAC, and RFD is used in place of NFRD when referring to those two bus lines. Except for that terminology, the operation of these lines is identical to the sequence just described.

3. Data Lines. The IEEE-488 bus uses 8 data lines that allow data to be transmitted or received one byte at a time. These lines, which use the convention DIO1 through DIO8 rather than the usual DØ through D7 terminology, are used to transmit both data and the multiline commands, and are bi-directional. Like the remaining bus lines, the data lines are inverted so that low is true.

4.3 IEEE-488 SET-UP PROCEDURE

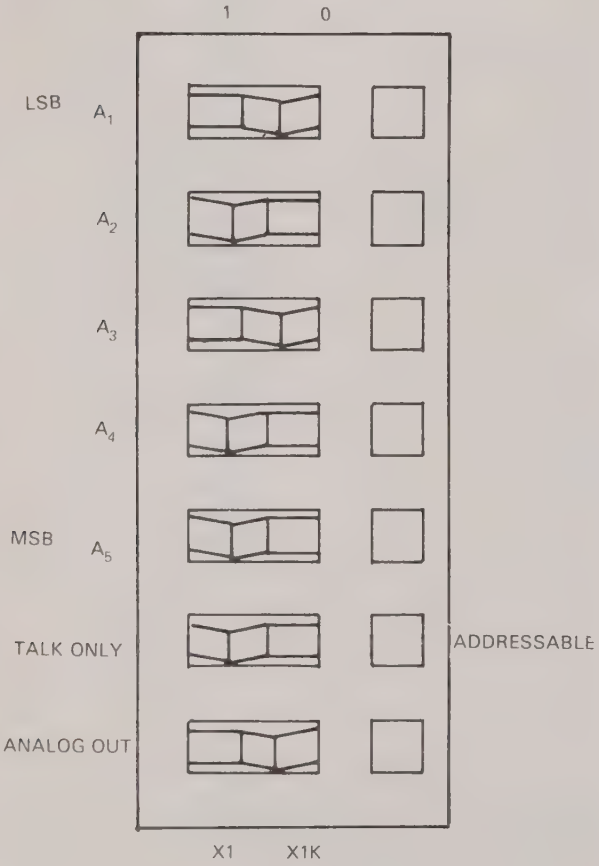
Before the Model 181 can be used with the IEEE-488 bus, the IEEE mode and primary address selector switches must be set to the appropriate positions. Also, the instrument must be connected to the bus with a suitable IEEE-488 connector as described in this section. The IEEE-488 connector and associated switches may be found in the lower left corner of the rear panel.

1. IEEE Mode Selection. The Model 181 may be set for either talk only (TO) or addressable operation by setting the TO/ADDRESSABLE switch on the rear panel to the desired position. In the addressable mode, the unit may be controlled by commands given over the bus. For a description of these commands, refer to paragraphs 4.4 and 4.5. When in the talk only mode, the Model 181 will ignore any commands given over the bus, but will transmit its normal data string to an external device one byte at a time, as requested. For formatting of the data string, see paragraph 4.6.

2. Primary Address Selection. If the Model 181 is to be used in the addressable mode, the primary address switches must be set to the correct value. The method used to determine the primary address depends on the controller used, but, generally, the numeric value specified in the controller's programming language must be the same as the numeric value set with the Model 181's primary address switches. As shown in Figure 4-3, the Model 181 primary address in set to 5 at the factory; however, any value between 0-30 may be used as long as the value used in the controller program agrees with the selected value on the instrument.

NOTE

Both the primary address switches and the TO/ADDRESSABLE switch are read only upon power-up. If the switch positions are changed, the instrument must be turned off and then powered-up again before it will recognize the new switch conditions.



NOTE

The switching positions in the figure are such that the Primary Address = 5(00101) and the unit is in the Addressable Mode. The Analog Output is in the X1 configuration.

Figure 4-3. Primary Address and IEEE Mode Switches

3. Bus Connections. The Model 181 should be connected to the bus with a suitable IEEE cable and connector. The IEEE connector on the unit is on the rear panel next to the primary address switches as shown in Figure 4-4. Note that the maximum cable length for any IEEE device is normally 20 meters. If many devices are connected to the bus, shorter cable lengths may be required. The Keithley Model 7008 IEEE cable is ideal for connecting the instrument to the bus.

Contact designations for the rear panel IEEE connector (J1006 on schematic number 30583) are listed in Table 4-1. Both the IEEE-488-1978 conventions and Keithley designations are shown in the table. For contact identification, refer to Figure 4-4. Contact 1 through 12 are along the top of the connector in sequence, while contacts 13 through 24 appear along the bottom edge.

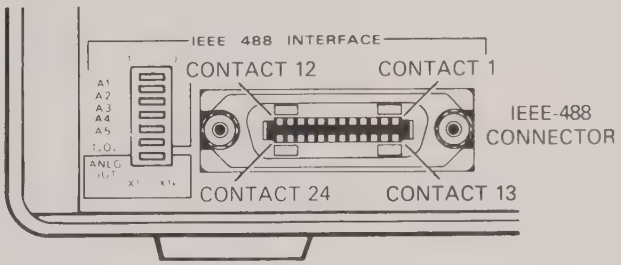


Figure 4-4. IEEE Contact Configuration

4.4 BUS COMMANDS

The Model 181 may be given a number of special bus commands through the IEEE-488 interface. These commands are grouped into the following types: single line commands, universal commands, and addressed commands. These commands are summarized in Table 4-2 and are discussed in the following paragraphs.

1. Single Line Commands. Each of the single line commands is sent by setting the appropriate bus line true (low) as follows:
   A. ATN, Attention. The ATN command is sent when the information on the data bus is a universal or addressed command. These commands will be described in more detail in the following paragraph. When the ATN line is false, the byte on the data bus is considered to be data. The Model 181 will respond to the appropriate universal and addressed commands when ATN is true and the device-dependent commands when ATN is false, assuming it is properly addressed.
   B. END. The END command is sent by setting the EOI line true during the last byte of data transfer. This command will be sent by the Model 181 during the last byte of its data string if programmed to do so as outlined in paragraph 4.5.
   C. REN, Remote Enable. The controller sends this command to all devices on the bus when remote operation is desired. The Model 181 will respond by setting itself up for remote operation as indicated by the front panel REMOTE annunciator light.
   D. IFC, Interface Clear. The IFC command is sent by setting the IFC line true. It sets the bus to a known state. The Model 181 will respond by cancelling the TALK and LISTEN front panel indicator lights if the unit was previously in those modes.

Table 4-1. IEEE Contact Designations

Contact Number	IEEE-488 Convention	Keithley Designation (J1006)	Type
1	DIO1	IBØ	Data
2	DIO2	IB1	Data
3	DIO3	IB2	Data
4	DIO4	IB3	Data
5	EOI (24)*	EOI	Management
6	DAV	DAV	Handshake
7	NRFD	RFD	Handshake
8	NDAC	DAC	Handshake
9	IFC	IFC	Management
10	SRQ	SRQ	Management
11	ATN	ATN	Management
12	SHIELD	BUS COMMON	Ground
13	DIO5	IB4	Data
14	DIO6	IB5	Data
15	DIO7	IB6	Data
16	DIO8	IB7	Data
17	REN (24)*	REN	Management
18	Gnd, (6)*	BUS COMMON	Ground
19	Gnd, (7)*	BUS COMMON	Ground
20	Gnd, (8)*	BUS COMMON	Ground
21	Gnd, (9)*	BUS COMMON	Ground
22	Gnd, (10)*	BUS COMMON	Ground
23	Gnd, (11)*	BUS COMMON	Ground
24	Gnd, LOGIC	BUS COMMON	Ground

*Numbers in parentheses refer to the signal ground return of the referenced contact number. EOI and REN signal lines return on contact 24.

Table 4-2. Bus Command Summary

Type	Command	Affect On Model 181
Single Line	ATN	Classifies Data Bus as Data or Commands.
	END	Set EOI low during last data byte.
	REN	Set unit for remote operation.
	IFC	Cancel Talk and Listen.
	SRQ	Sent by 181 to request service.
Universal	DCL	Return to default conditions.
	LLO	Lock out front panel controls.
	SPE	Send status byte.
	SPD	Disable serial poll sequence.
	UNT	Remove from talk mode.
	UNL	Remove from listen mode.
Addressed	SDC	Return to default conditions.
	GET	Trigger conversion in T2 and T3 modes.
	GTL	Return to local operation.

E. SRQ, Service Request. The SRQ command is sent to the controller by external devices when service is required. The Model 181 will implement this command when in the appropriate bus response mode as described in paragraph 4.5.

2. Universal Commands. The IEEE universal commands are sent over the data bus when ATN is true. The following paragraphs describe the effect of these commands on Model 181 operation.
   A. DCL, Device Clear. The Model 181 will return to the power-up default conditions as outlined in paragraph 4.5.
   B. LLO, Local Lockout. When the controller sends a LLO over the bus, all devices equipped to implement this command will respond by locking out their controls. After a LLO command has been sent, the Model 181 front panel controls are no longer operative. Local control of the instrument may be restored by sending a GTL command as described in the next paragraph.
   C. SPE, Serial Poll Enable. The SPE command is normally sent by the controller after receiving a SRQ command to determine which device initiated the service request. The Model 181 will respond by sending its status byte when addressed to talk after the SPE command is sent.
   D. SPD, Serial Poll Disable. This command disables the serial polling sequence.
   E. UNT, Untalk. The controller sends this command to remove any talkers from the bus. The Model 181 will return to its idle state if it was previously in the talk mode, and the front panel TALK light will go out.
   F. UNL, Unlisten. The controller sends this command to remove all listeners from the bus. The Model 181 will go to the idle state if previously set to listen, and the front panel LISTEN light will go out.
3. Addressed Commands. Each of the addressed commands is sent to a specific device on the bus. The device is selected on the basis of its primary address. The Model 181 will respond to these commands only if the primary address sent over the bus preceding these commands is the same as selected by the rear panel address switches. All these commands are implemented by addressing the Model 181 to listen.
   A. SDC, Selective Device Clear. This command performs the same function as DCL except that only the addressed device will respond. The Model 181 will return to the default conditions outlined in paragraph 4.5.
   B. GET, Group Execute Trigger. This command will trigger a conversion within the Model 181. The GET command must be used before requesting data or the status word when in the T2 or T3 bus response mode.
   C. GTL, Go To Local. The Model 181 will return to the local mode if the LLO command was previously given. The front panel controls will once again function after this command is sent.

4.5 DEVICE-DEPENDENT COMMANDS

The device-dependent commands allow the user to send the Model 181 commands that perform the same operations as all the front panel control switches except power on-off. In addition, there are a number of commands that control parameters which are not available from the front panel. Each command is entered as an ASCII character followed by a specific parameter that is then sent over the bus by the controller. The IEEE bus treats these commands as data in that the ATN line is false when the commands are transmitted.

A number of commands may be grouped together as long as the total number of characters sent at one time is no greater than 18. Before a command or command string is executed, the ASCII character X must be sent. Commands sent without an X (execute) will be retained within the Model 181 command buffer until the execute character is received.

The device-dependent commands affect the condition of the status word within the Model 181. The status word may be obtained from the unit by using the commands covered in this section. For formatting of the status word, see paragraph 4.8. Illegal commands will cause no mode changes in the Model 181. However, the status byte condition will change as described in paragraph 4.7. Legal Model 181 commands are listed in Table 4-3, and are covered in the following paragraphs.

1. Range. The voltage range of the Model 181 may be set to the desired value by sending the ASCII character R followed by a number from 1 through 7. Each number represents one of the voltage ranges as described in Table 4-4, which also lists the readings rates for the various ranges.
2. Bus Response Mode. The bus response mode determines whether or not the Model 181 will send the SRQ command when data is ready to be sent or an error condition exists. The bus response mode may be programmed with the following commands:

   MØ, Standard. Send no SRQ. The status byte will still be updated and may be read as described in paragraph 4.7.

   M1, Interrupt. The Model 181 will send the SRQ command to the controller when a reading is triggered or if an error condition exists. If more than one device is on the bus, the user must do a serial poll sequence to determine which device has requested service.

3. Trigger Mode. The trigger mode affects the way the Model 181 updates its data output buffer. The instrument will update the buffer on a continuous or one-shot basis each time a talk or GET command is received, depending on the mode of operation. Once the data reading is in the buffer, the Model 181 will transmit the data string the next time a data request is made by another bus device. For formatting of the data string, refer to paragraph 4.6.

Table 4-3. Device-Dependent Command Summary

Command Character	Controls	Parameter Description
R	Voltage Range	See Table 4-4
M	Bus Response Mode	0, Non SRQ 1, Send SRQ
T	Trigger Mode	0, Continuous On Talk 1, One-Shot On Talk 2, Continuous On GET 3, One-Shot On GET
Y	Terminator	*
P	Filter	0, Disable Filter Entirely 1, FILTER Off 2, FILTER On
D	Damping	0, DAMPING Off 1, DAMPING On
Z	Zero	0, ZERO Out 1, ZERO In
B	Display Resolution	0, 5½ Digits 1, 6½ Digits
K	EOI	0, Send EOI 1, Send No EOI
U	Status Word	**
X	Execute Other Commands	**

*Any ASCII character except other command characters and E, ., +, −, (space).
**No parameter specified for this command.

T0, Continuous On Talk. The data buffer will be continuously updated at a rate listed in Table 4-4. As indicated, the rate will depend on the voltage range used. When the unit is addressed to talk, it will respond by sending its data string.

Table 4-4. Range Commands

RANGE	DC Volts	Reading Rates
R1	.002	4rdg/sec
R2	.02	4rdg/sec
R3	.2	4rdg/sec
R4	2	8rdg/sec
R5	20	8rdg/sec
R6	20	8rdg/sec
R7	1000	8rdg/sec

T1, One-Shot On Talk. The data output buffer is updated only once each time the instrument is addressed to talk. The data string will then be sent when the unit is addressed to talk.

T2, Continuous On GET. The data buffer will be continuously updated after a GET command is received. When in this mode, the unit must receive a GET command before attempting to read data.

T3, One-Shot On GET. The instrument will update its data output buffer once each time a GET command is received. As with the T2 mode, the GET command must be received before attempting to read data.

NOTE

Care should be taken when using the T2 or T3 modes. The Model 181 will not respond to a data request unless a GET command is received first, even if addressed to talk in the normal manner. Depending on the controller used, failure to observe this precaution may result in a bus "hang up". For further details, consult the controller's manual as to potential problems when using the IEEE-488 bus.

4. Programmable Terminator. The data string of the Model 181 is normally terminated with one or two ASCII characters. The default terminator sequence is (CR LF), but this may be changed by sending the ASCII character Y followed by the desired terminator. For example, if the desired terminator is the letter H, the sequence YHX must be sent over the bus.

Other Model 181 command letters may not be used as terminator characters. These include: B,D,M,P,R,T,Y,X,K,U. Special terminator characters must be sent for some sequences. For example, the ASCII (DEL) character will suppress the terminator entirely. An ASCII (CR) will change the terminator sequence to (LF CR), while as ASCII (LF) will restore the terminator to the (CR LF) default sequence. For example, sending the command Y(LF)X to the Model 181 will restore the terminator to its default (CR LF) value.

5. Filter Commands. The operating mode of the internal 3-pole digital filter may be altered by commands given over the bus. Through the use of these commands, the user may change the RC time constant of the filter as described in paragraph 2.8. The filter commands are described in the following paragraphs.

PØ, Filter Disabled. This command entirely disables the internal filter, and is not available from the front panel. The Model 181 may be operated in this mode to obtain raw, unfiltered data readings, or if custom external filter designs are used. Care should be taken when operating the instrument in this mode as internally generated noise spikes may occur in the readings.

P1, Filter 1 Enabled. This Command will perform the same function as disabling the filter from the front panel. The Model 181 FILTER indicator light will go out if Filter 2, as described below, was previously enabled.

P2, Filter 2 Enabled. This command performs the same operation as enabling the filter from the front panel. After the P2 command is given, the front panel FILTER indicator will turn on.

6. Damping Commands. The damping commands further control the operation of the internal filter. When the damping is off, the microprocessor within the Model 181 determines whether or not the filter is enabled. The operation of the damping commands is described in the following paragraphs.

DØ, No Damping. With the damping off, the internal microprocessor determines when the internal filter is enabled. For steady-state inputs, the filter will be continuously enabled. When the input voltage level changes, the microprocessor disables the filter to permit rapid display update. Once the reading is within 25 digits of the final value on the 2mV range, and within 6 counts on the remaining ranges, the MPU then enables the filter once again.

D1, Damping Enabled. In this mode, the filter is permanently enabled. This mode of operation is normally used only for signals whose levels change relatively slowly.

The filter and damping commands may be used in various combinations to achieve the desired instrument reponse. For a more complete discussion of the interaction between these two commands, refer to paragraph 2.8.

7. Zero. The zero serves as a baseline suppression. Once the baseline is stored, all readings taken with the zero enabled will be the difference between the actual reading and the stored baseline. This command is especially useful for nulling out stray voltages picked up by connections to the test set up. The zero is controlled by sending one of the following commands over the bus.

ZØ, Zero Out. The zero will be disabled, as indicated by the off state of the front panel ZERO light.

Z1, Zero In. The zero will be enabled; the front panel zero indicator light will turn on.

8. Display Resolution. The display may be set to 5½ or 6½ digit resolution by sending the appropriate command. These commands affect only the display; the bus always contains 6½ digit information. In the 5½ digit mode, the least significant digit will be rounded off.

BØ, 5½ Digits.
B1, 6½ Digits.

9. EOI. The EOI line is usually set true by a device during the last byte of data transmission. The Model 181 EOI operation may be programmed with one of the following commands.

KØ, Send EOI during last byte of data.
K1, Send no EOI.

10. Status Word Command.The status word may be accessed with the following command sequence: UX. After this command is transmitted, the status word will be sent instead of the data string the next time data is requested from the unit. Note that a GET command must be transmitted first if the unit is operating in the T2 or T3 trigger modes. For formatting of the status word, refer to paragraph 4.8.

11. Default Conditions. Upon power-up, the Model 181 will assume the default conditions listed in Table 4-5. The unit will also revert to these conditions after receiving a DCL or SDC command over the bus. For a further description of these commands, refer to paragraph 4.4. These conditions may be checked by accessing the status word with the UX command sequence. For formatting of the status word, refer to paragraph 4.8.

Table 4-5. Default Conditions

R7	1000V range
MØ	Non SRQ
TØ	Continuous On Talk
Y(LF)	Terminator is (CR)(LF)
P1	Filter out on front panel
DØ	No Damping
ZØ	Contents of Zero Buffer equal zero
BØ	5½ Digit Resolution
KØ	Send EOI

4.6 DATA FORMAT

The Model 181 has two modes of operation over the IEEE bus. When in the TO (talk only) mode, the instrument will transmit its data string as requested by the external device. When the Model 181 is in the addressable mode, it must first receive a talk command from the controller. That talk command is derived from the primary address set by the address switches on the rear panel. Once the correct talk command is received, the Model 181 will send its data in bit-parallel, byte-serial fashion over the bus, as requested by the acceptor. The Model 181 data string contains between 16-18 ASCII characters as shown in Figure 4-5. The actual number of characters will depend on the number of programmed terminator characters (0-2).

The first string character will show the type of readings: an N will be transmitted if the reading is normal, while the O and Z characters indicate overflow and zeroed readings respectively. The next three characters indicate the function. Since the Model 181 reads only DC voltages, these characters will always read DCV.

The fifth character is the sign of the reading, while the next seven characters form voltage reading itself. The data is normalized so that only one digit appears to the left of the decimal point. For a normal reading, this digit can have only the values 0 or 1. When the instrument is in overflow, however, the most significant digit will be a 4; in addition, the remaining digits will show all zeroes while the overflow condition exists.

The next three characters show the exponent value. Since the reading is normalized, the voltage range of the Model 181 can be derived from the exponent value as shown in Table 4-6. On the 2mV range, the exponent will be -3. Switching to the 20mV range changes the exponent to -2. With each upwards range change, the exponent changes accordingly, until it reaches its maximum value of +3 on the 1000V range.

Table 4-6. Data String Exponent Values

Exponent	Range
−3	2mV
−2	20mV
−1	200mV
+0	2 V
+1	20 V
+1	200 V
+3	1000 V

The last two characters in the data string form the terminator sequence. Figure 4-5 shows the default value of (CR LF), but other programmed terminators will, of course, change the data string. No terminator will be sent if the terminator sequence was previously suppressed with the appropriate terminator command.

As an example of the data format, assume that the following data string is sent by the Model 181: NDCV-0.194557E-1 CR LF. A quick inspection reveals that a negative DC voltage is being measured. The data reading is 0.194557, but the exponent shows that the decimal point must be moved one place to the left, resulting in a final interpretation of -0.0194557 VDC. Finally, since the exponent has a value of -1, the instrument was on the 200mV range when the reading was taken.

4.7 STATUS BYTE FORMAT

The Model 181 has a available status byte that will allow the user to check certain error conditions, as well as SRQ and overflow status. The general format of the status byte is shown in Figure 4-6. Note that the IEEE-488 bits are designated DIO1 through DIO8; these bits correspond to bit 0 through bit 7 in the usual binary convention.

The status byte may be obtained by first sending the SPE (Serial Poll Enable) command and then addressing the instrument to talk. The unit will then place the status byte on the the bus. After the status byte is read, the serial poll sequence should be disabled with the SPD (Serial Poll Disable) command.

The status byte may be accessed whether or not an SRQ was generated by the Model 181. Care must be taken doing the serial polling sequence; if the command sequence is too slow, the instrument may send the wrong status byte. Also, the byte must be read before the next data string is requested or an incorrect value may be returned.

If the bus response mode was previously set to M1, the Model 181 will send an SRQ command over the bus when an error condition exists or when data is requested from the unit. If more than one device is on the bus, the user must then use the SPE command to determine which device is requesting service. If the service request was initiated by the Model 181, bit 6 (DIO7) of its status byte will be set. If this bit is cleared, the service request was not made by the Model 181.

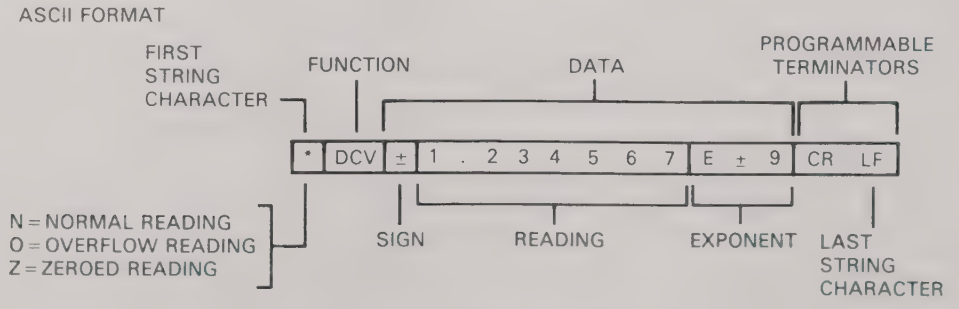


Figure 4-5. IEEE-Bus Data Format

The status byte may be further checked to determine other operating parameters. If bit 5 of the status byte is set, an error condition exists.

Table 4-7 lists the conditions of the important bits along with the resulting messages. Note that even if 5 bit is cleared, bit 0 may be set if the Model 181 is in overflow.

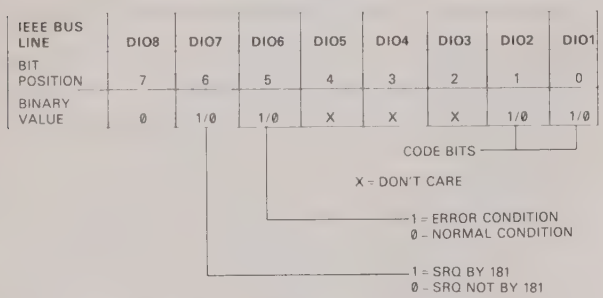


Figure 4-6. Status Byte Format

Table 4-7. Error and Data Code Summary

Bit Position			
5	1	0	Message
0	0	0	Normal
0	0	1	Overflow
1	0	0	Illegal Command (e.g., A)
1	0	1	Illegal Command Option (e.g., K2)
1	1	0	Illegal Command String Length (More than 17 characters.)

4.8 STATUS WORD FORMAT

The various modes of the Model 181 are controlled by the conditions of the various bytes in the status word. Each mode such as range, resolution, etc. is assigned a number equal to its programmed value. The status word may be checked to determine the various operating modes of the unit.

When the UX command sequence is sent over the bus, the Model 181 will transmit the status word the next time data is requested from the unit. This status word is sent as ASCII characters forming a string up to 24 bytes in length. The format of the status word is as follows: R B Z P D M T K Y, where R is the range, B is the resolution, etc. The EOI and terminator modes during status word transmission remain as programmed by their separate commands.

NOTE

A GET command must be sent first in the T2 or T3 trigger modes.

The returned value for each mode except the Y (terminator) is equal to the previously programmed number. For example, if the range was previously set to R5 (20VDC), the first character in the status word will be the ASCII character 5.

The returned terminator status character has a slightly different format. Its value is derived by first masking off the four highest-ordered bits of the last terminator character by ANDing the byte with 00001111. The result is then ORed with 00110000. For example, the last byte in the default terminator is a LF, or ASCII 10. Masking with 00001111 yields 00001010. ORing this value with 00110000 gives the final result of 00111010, which is returned as an ASCII colon (:). An example of returned values for the status word 5 0 1 0 0 0 1 1 : is shown in Table 4-8.

Table 4-8. Status Word Example

Function	Returned Value	181 Status
Range	5	20 VDC
Resolution	0	5½ digit
Zero	1	Zero in
Filtering	0	No filtering
Damping	0	No damping
SRQ	0	No SRQ
Trigger	1	One shot on talk
EOI	1	No EOI
Terminator	:	CR LF

Two precautions must be taken when accessing the status word. It must be immediately read by the controller, or the present word will be lost. Also, since the terminator characters may not be printed out by some controllers, care should be taken when interpreting the terminator status character. Consult the controllers manual for further information.

4.9 PROGRAMMING EXAMPLE

The programming example given in this subsection uses Hewlett Packard Model 85 BASIC computer language and is intended only to be an example of possible programming configurations. The HP-85 was chosen for these examples because it has a large number of BASIC commands that control IEEE-488 operation. Other controllers may be equally suitable for use with the Model 181; consult the controller's operating manual for more information.

A partial list of important HP-85 BASIC statements that control bus operation is shown in Table 4-9. Many of these commands have a 3-digit argument that is essential to bus operation. The first digit in this 3-digit number is the HP-85 interface select code, and is set to 7 at the factory; the last two digits are the primary address of the external device. Each example in Table 4-9 assumes that the Model 181 primary address is at its factory set value of 5.

Many of the BASIC statements use only the interface select code. Other statements may be used with or without the primary address, depending on the desired command. CLEAR 7 for example, sends a DCL over the bus, while CLEAR 705 sends an SDC to device number 5 (in this case, the Model 181). Note that the first statement will affect all

devices on the bus equipped to implement the DCL command, while the second statement will affect only the addressed device.

Two of the more important statements in Table 4-9 are the ENTER and OUTPUT statements. The ENTER statement addresses device 5 to talk and then reads the entire data string into the computer, where it is stored as A$. The OUTPUT statement addresses device 5 to listen and then sends the device-dependent command string to the Model 181.

Table 4-9 lists only the statements most important to Model 181 operation. For a more complete list of HP-85 statements that affect the Model 181, consult the HP-85 operator's manual.

A simple program to control the Model 181 with an HP-85 is shown in Figure 4-7. The program shown is by no means complete, but is merely intended to serve as a starting point for more complex programs. This program will allow the user to control the following aspects of Model 181 operation over the bus:

1. Send device-dependent commands.
2. Input the data string or status word into the computer and display it on the CRT.
3. Send the following additional commands: REN, DCL, SDC, LLO, GTL, GET.
4. Check for error conditions by accessing the Model 181 status byte.

Once the program is run, the user is prompted as to the desired course of action. Depressing the HP-85 k1 key at this point will give access to the device dependent commands. Once the appropriate command is sent, the data string is read and then displayed on the CRT. At the same time, the status byte is checked, and any error messages are displayed on the screen. Note that the status word may be checked at this point by sending the UX command sequence; the operation is very similar except that the returned string is the status word instead of normal data. Remember that a GET command must be sent first in the T2 or T3 bus response modes.

NOTE

The instrument should be placed in the remote mode with the REN command first.

The remainder of the commands may be asserted by depressing the appropriate k function key. For example, to lock out the front panel controls, the LLO command is transmitted by using the k6 function key on the HP-85.

The program in Figure 4-7 makes use of several HP-85 statements not listed in Table 4-9. The RESUME statement, for example, returns the ATN line to its false state after some commands that leave ATN true. Also, the SEND statement is used to send Untalk and Unlisten commands to the Model 181 after data or commands are transmitted. These commands are not really necessary unless other devices are used on the bus at the same time. For further details on the operation of these and other BASIC statements, refer to the HP-85 manual.

Some precautions are in order when using the program in Figure 4-7. First of all, the ENTER statement used in lines 150 and 330 of the program assumes that the normal (CR LF) terminator sequence will be sent by the Model 181 at the end of its data string. Other terminator sequences may require the use of the ENTER USING statement described in the HP-85 manual. Secondly, the HP-85 has no provision for handling situations where an IEEE-488 device does not respond to a bus command. Thus, the HP-85 computer may hang up if the program is used with a Model 181 set to a different primary address, or if the Model 181 is disconnected from the bus or turned off.

Table 4-9. HP-85 BASIC IEEE-488 Statements

Statement	Action	Affect on Model 181
ABORTIO 7	Send IFC	Cancel Talk, Listen. Remote not affected.
CLEAR 7	Send DCL.	Return to default conditions.
CLEAR 705	Send SDC.	Return to default conditions.
ENTER 705; A$	Device 5 addressed to talk. Data placed in A$.	Transmit data string or status word.
LOCAL 705	Send GTL.	Return to local control.
LOCAL LOCKOUT 7	Send LLO.	Front panel controls disabled.
OUTPUT 705; A$	Device 5 addressed to listen. Transmit A$.	Receive device-dependent command string.
REMOTE 705	Send REN.	Set for remote operation.
RESET 7	Send IFC, Cancel REN.	Cancel Talk, Listen, Remote.
SPOLL (705)	Send SPE, obtain status byte, send SPD.	Send status byte.
TRIGGER 7	Send GET to all devices.	Trigger conversion in T2 and T3 modes.
TRIGGER 705	Send GET to device 5.	Trigger conversion in T2 and T3 modes.

PROGRAM	COMMENTS
10 DIM A$[25]	SET A$ FOR 25 CHARACTERS
20 ON KEY# 1,"DEVICE" GOSUB 120	DEFINE KEY LABELS
30 ON KEY# 2,"REN" GOSUB 540	
40 ON KEY# 3, "GET" GOSUB 320	
50 ON KEY# 4,"DCL" GOSUB 380	
60 ON KEY# 5,"SDC" GOSUB 420	
70 ON KEY# 6,"LLO" GOSUB 460	
80 ON KEY# 7,"GTL" GOSUB 500	
90 CLEAR @ KEY LABEL	
100 DISP "SELECT OPTION"	
110 GOTO 110	WAIT FOR OPTION SELECTION
120 DISP "DEVICE COMMAND"	
130 INPUT A$	TYPE IN DEVICE—DEPENDENT COMMAND
140 OUTPUT 705 ;A$	TRANSMIT COMMAND TO 181
150 ENTER 705 ; B$	OBTAIN DATA STRING OR STATUS WORD
160 SEND 7 ; UNT @ RESUME 7	
170 S = SPOLL(705)	OBTAIN STATUS BYTE FROM 181
180 DISP @ DISP B$	DISPLAY DATA ON CRT
190 IF S < > Ø THEN 230	IF STATUS BYTE < > Ø GOTO LINE 230
200 DISP @ DISP "PRESS 'CONT'"	
210 PAUSE	
220 GOTO 20	
230 IF BIT(S,6) = 1 THEN DISP "SER VICE REQUEST RECEIVED"	CHECK FOR SERVICE REQUEST
240 IF BIT(S,Ø) = 1 AND BIT(S,5) = Ø THEN DISP "OVERFLOW" @ GOTO 290	IS UNIT IN OVERFLOW?
250 IF BIT(S,5) = Ø THEN 290	
260 IF BIT(S,1) = Ø AND BIT(S,Ø) = Ø THEN DISP "ILLEGAL COMMAND" @ GOTO 290	ILLEGAL COMMAND?
270 IF BIT(S,1) = Ø AND BIT(S,Ø) = 1 THEN DISP "ILLEGAL COMMAND OPTION" @ GOTO 290	ILLEGAL COMMAND OPTION?
280 IF BIT(S,1) = 1 AND BIT(S,Ø) = Ø THEN DISP "ILLEGAL STRING L ENGTH"	ILLEGAL COMMAND STRING LENGTH?
290 DISP "PRESS 'CONT' "	
300 PAUSE	
310 GOTO 20	

Figure 4-7. Programming Example

PROGRAM	COMMENTS
320 TRIGGER 705	SEND GET
330 ENTER 705 ; B$	OBTAIN DATA STRING
340 DISP B$	DISPLAY DATA ON CRT
350 SEND 7 ; UNL UNT	
360 RESUME 7	
370 RETURN	
380 CLEAR 7	SEND DCL
390 SEND 7 ; UNL	
400 RESUME 7	
410 RETURN	
420 CLEAR 705	SEND SDC
430 SEND 7 ; UNL	
440 RESUME 7	
450 RETURN	
460 LOCAL LOCKOUT 7	SEND LLO
470 SEND 7 ; UNL	
480 RESUME 7	
490 RETURN	
500 LOCAL 705	SEND GTL
510 SEND 7 ; UNL	
520 RESUME 7	
530 RETURN	
540 REMOTE 705	SEND REN
550 RETURN	
560 END	

Figure 4-7. Programming Example Cont.

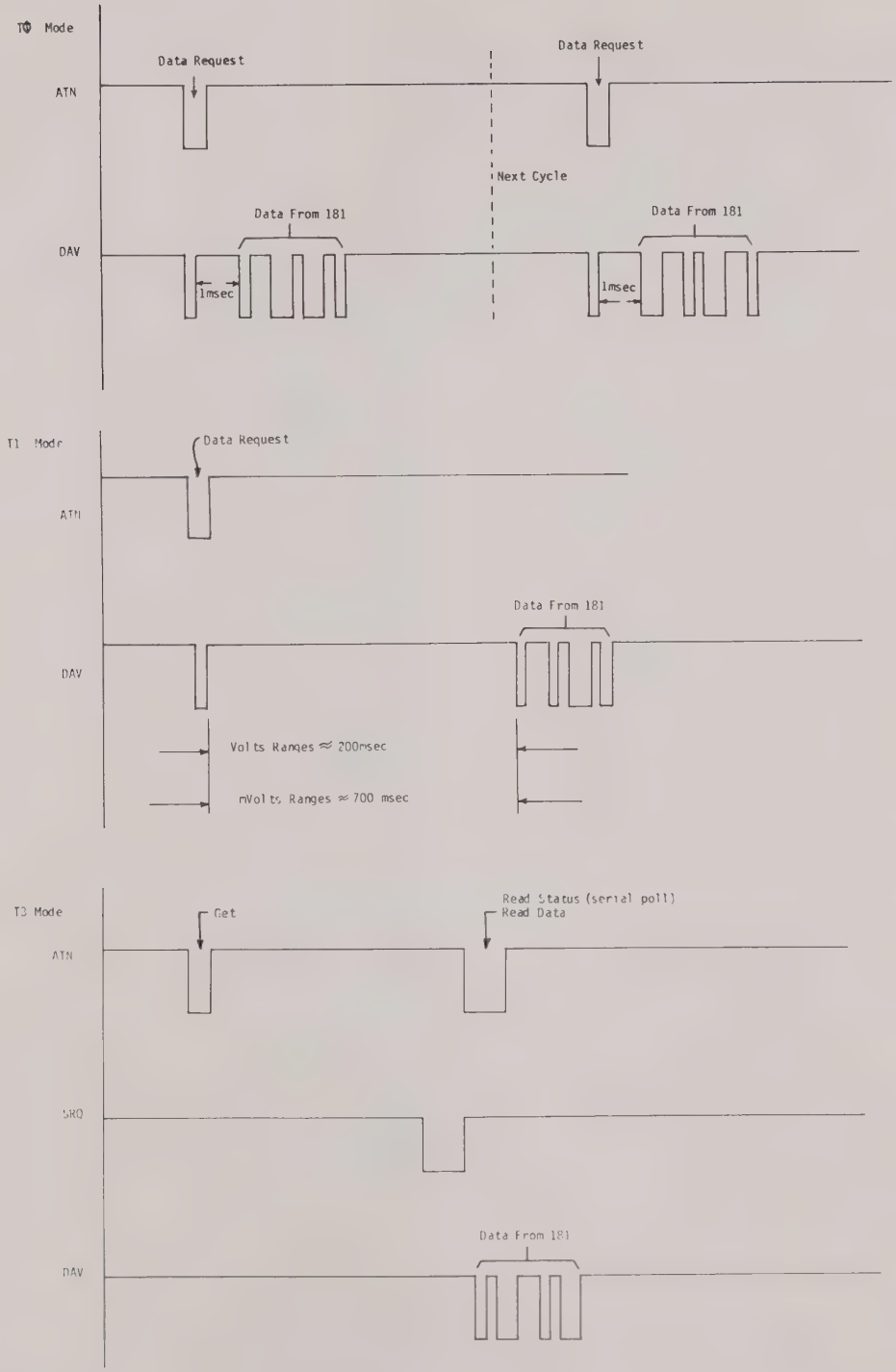
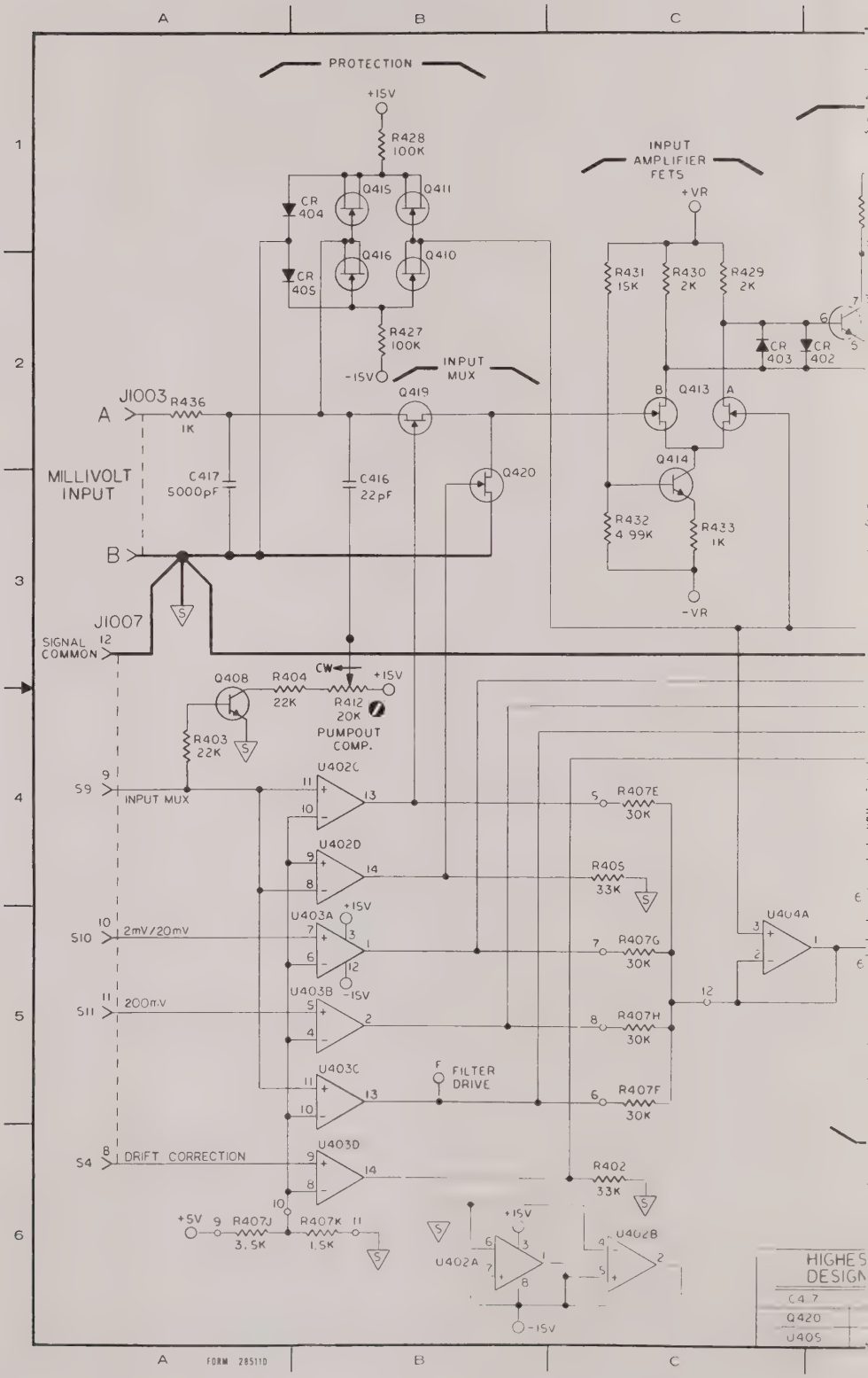
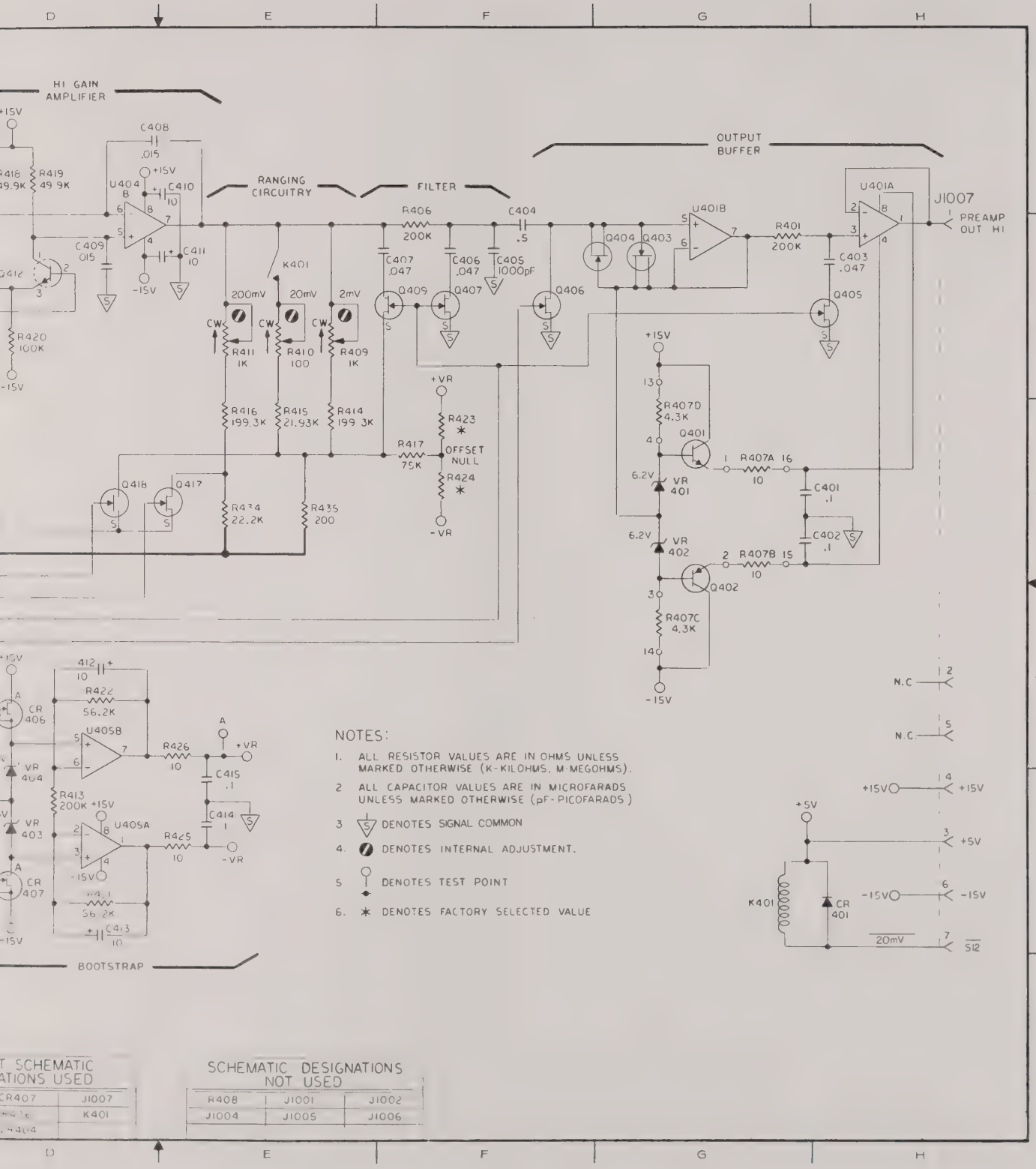


Figure 4-8. Timing Diagram


PROTECTION
+15V
R428 100K
CR 404
Q415
Q411
CR 405
Q416
Q410
R427 100K
-15V
INPUT MUX
INPUT AMPLIFIER FETS
+VR
R431 15K
R430 2K
R429 2K
CR 403
CR 402
Q413
Q414
R432 4.99K
R433 1K
-VR
J1003
A
R436 1K
Q419
MILLIVOLT INPUT
C417 5000pF
C416 22pF
Q420
B
J1007
SIGNAL COMMON
Q408
R404 22K
CW
+15V
R412 20K
PUMPOUT COMP.
R403 22K
S9
INPUT MUX
U402C
U402D
R407E 30K
R405 33K
S10
2mV/20mV
U403A
U404A
R407G 30K
S11
200mV
U403B
R407H 30K
U403C
F
FILTER DRIVE
R407F 30K
S4
DRIFT CORRECTION
U403D
R402 33K
+5V
R407J 3.5K
R407K 1.5K
U402A
U402B
-15V
A
B
C
FORM 285110
HIGHES
DESIGN
C4.7
Q420
U405



NOTES:

1. ALL RESISTOR VALUES ARE IN OHMS UNLESS MARKED OTHERWISE (K-KILOHMS, M-MEGOHMS).
2. ALL CAPACITOR VALUES ARE IN MICROFARADS UNLESS MARKED OTHERWISE (pF-PICOFARADS)
3. DENOTES SIGNAL COMMON
4. DENOTES INTERNAL ADJUSTMENT.
5. DENOTES TEST POINT
6. * DENOTES FACTORY SELECTED VALUE

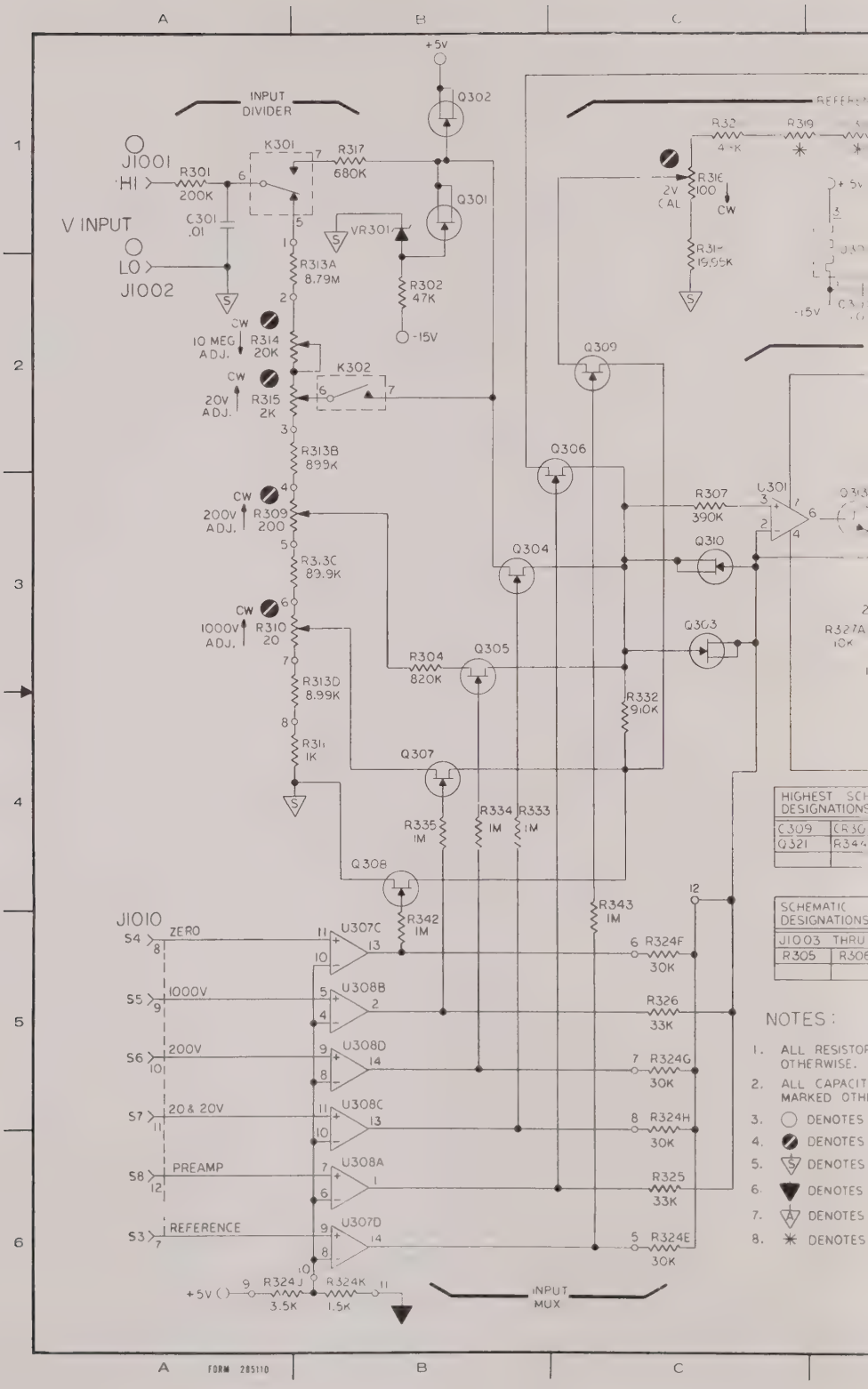
T SCHEMATIC ATIONS USED

CR407	J1007
[illegible]	K401

SCHEMATIC DESIGNATIONS NOT USED

R408	J1001	J1002
J1004	J1005	J1006

Figure 4-9. Nanovolt Preamp PC-526, Schematic Diagram, Dwg. No. 30586D


INPUT DIVIDER
V INPUT
J1001
HI
LO
J1002
R301 200K
C301 .01
K301
R317 680K
Q302
Q301
VR301
R313A 8.79M
R302 47K
-15V
R314 10 MEG ADJ.
R315 20V ADJ. 2K
K302
R313B 899K
R309 200V ADJ. 200
R313C 89.9K
R310 1000V ADJ. 20
R313D 8.99K
R31x 1K
Q309
Q306
Q304
Q305
Q307
Q308
R304 820K
R332 910K
R335 1M
R334 1M
R333 1M
R342 1M
R343 1M
R307 390K
U301
Q310
Q303
R32
R319
R31E 100
2V CAL
R31- 19.95K
+5V
-15V
J1010
S4 ZERO
S5 1000V
S6 200V
S7 20 & 20V
S8 PREAMP
S3 REFERENCE
U307C
U308B
U308D
U308C
U308A
U307D
R324F 30K
R326 33K
R324G 30K
R324H 30K
R325 33K
R324E 30K
R324J 3.5K
R324K 1.5K
INPUT MUX
HIGHEST SCH DESIGNATIONS
C309
CR30
Q321
R34
SCHEMATIC DESIGNATIONS
J1003 THRU
R305
R30
NOTES:
1. ALL RESISTOR OTHERWISE.
2. ALL CAPACIT MARKED OTH
3. DENOTES
4. DENOTES
5. DENOTES
6. DENOTES
7. DENOTES
8. DENOTES
FORM 285110

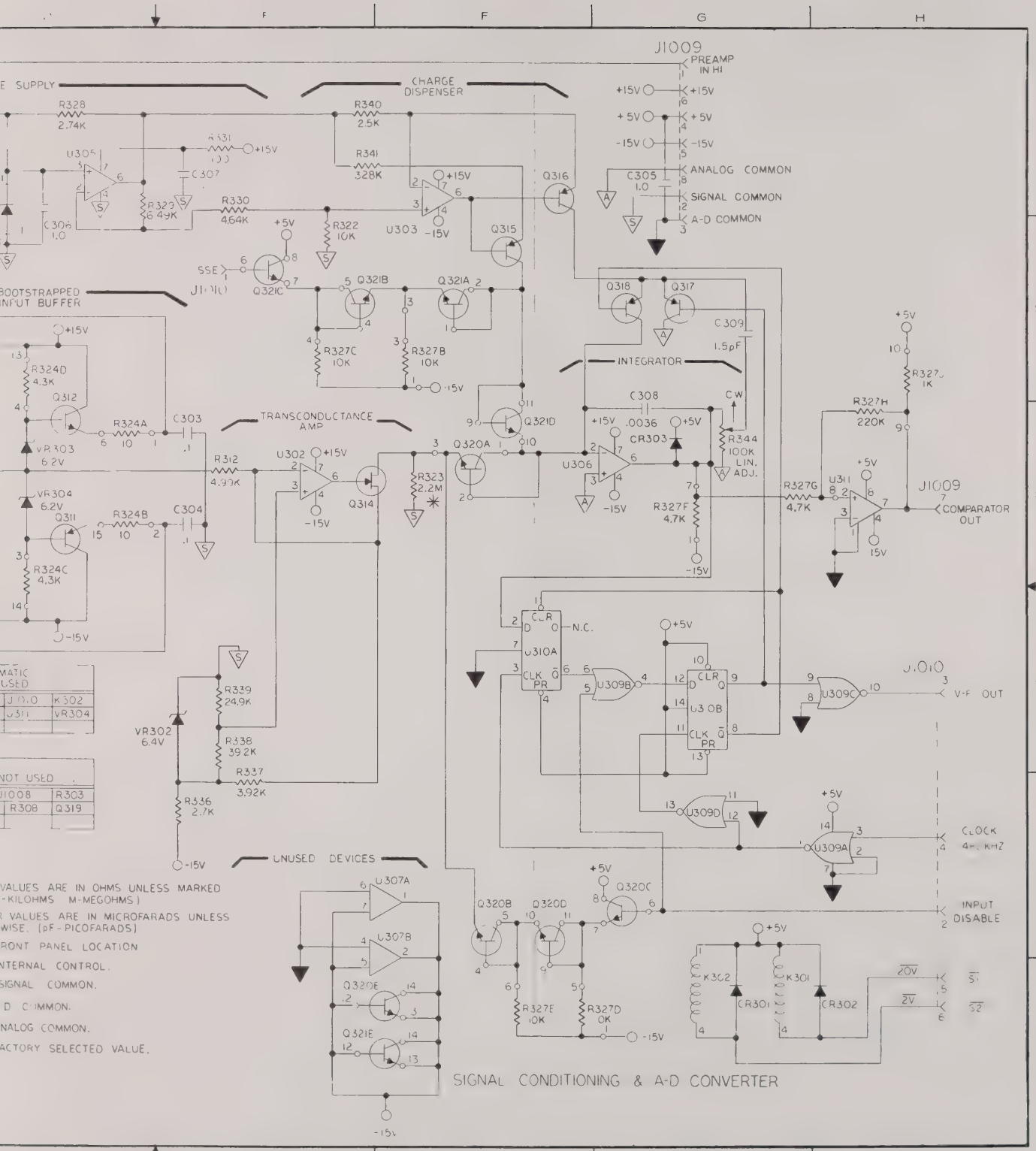
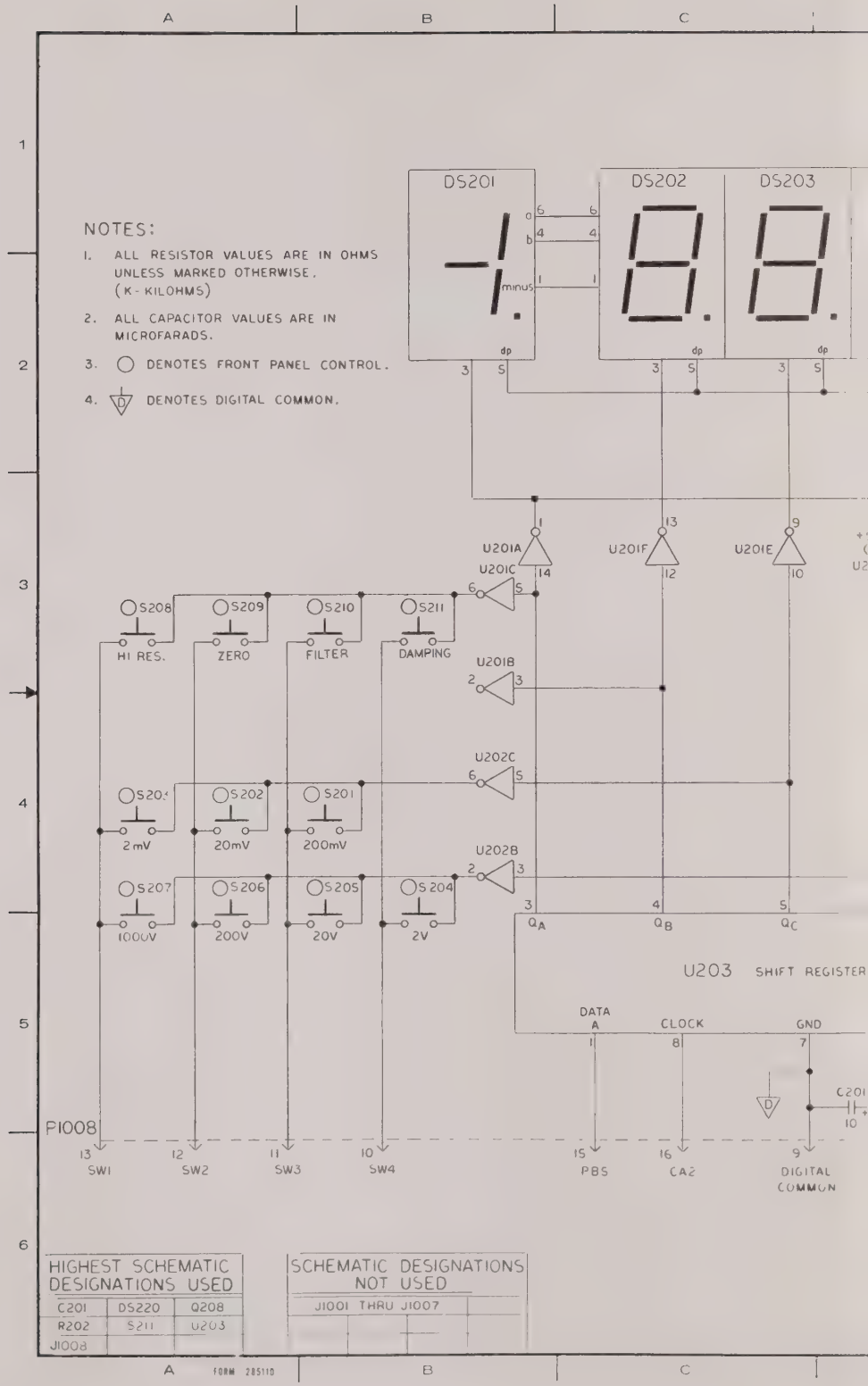


Figure 4-10. Analog Board PC-529, Schematic Diagram, Dwg. No. 30585D



HIGHEST SCHEMATIC DESIGNATIONS USED		
C201	DS220	Q208
R202	S211	U203
J1008		

SCHEMATIC DESIGNATIONS NOT USED
J1001 THRU J1007

FORM 285110

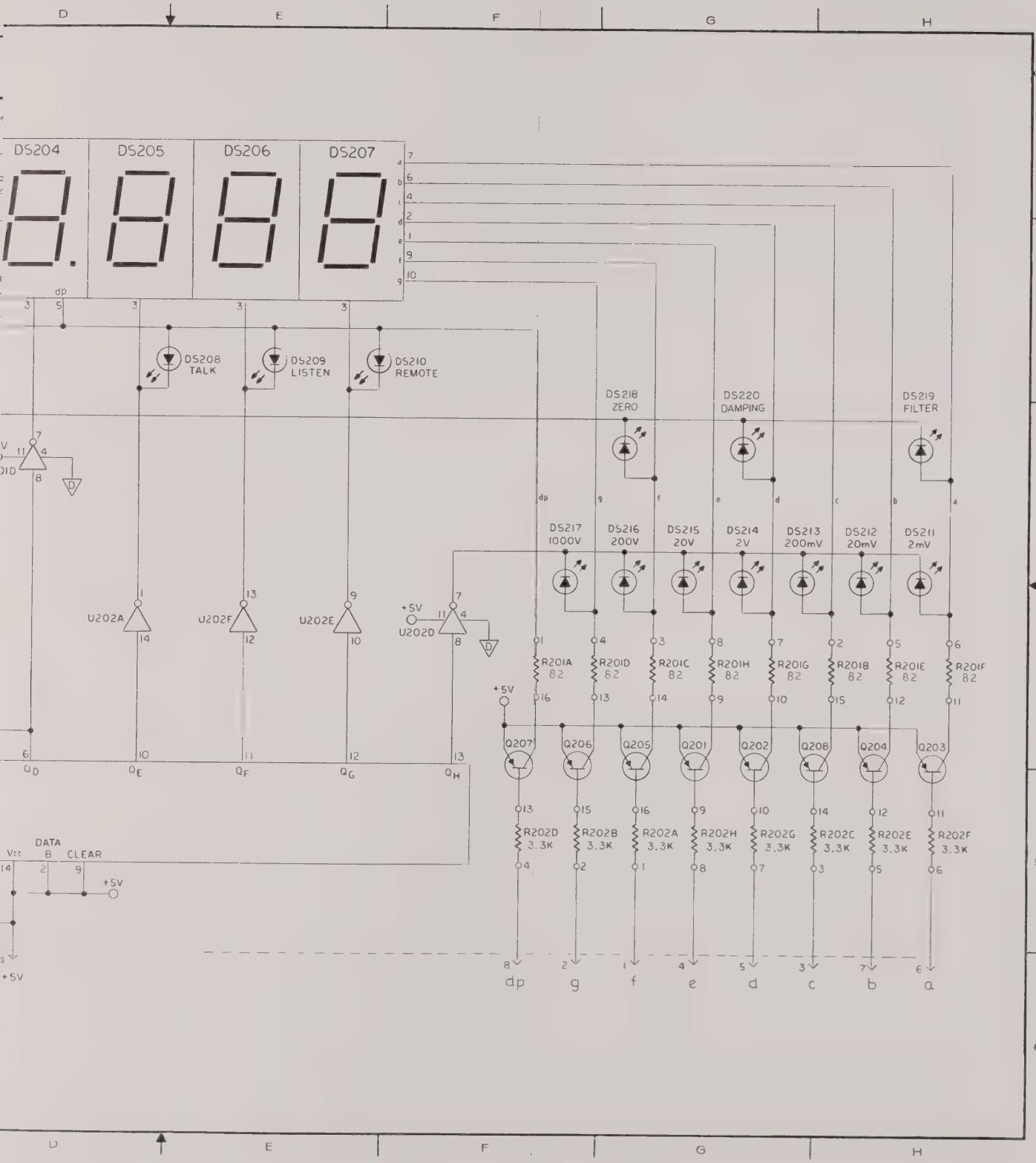
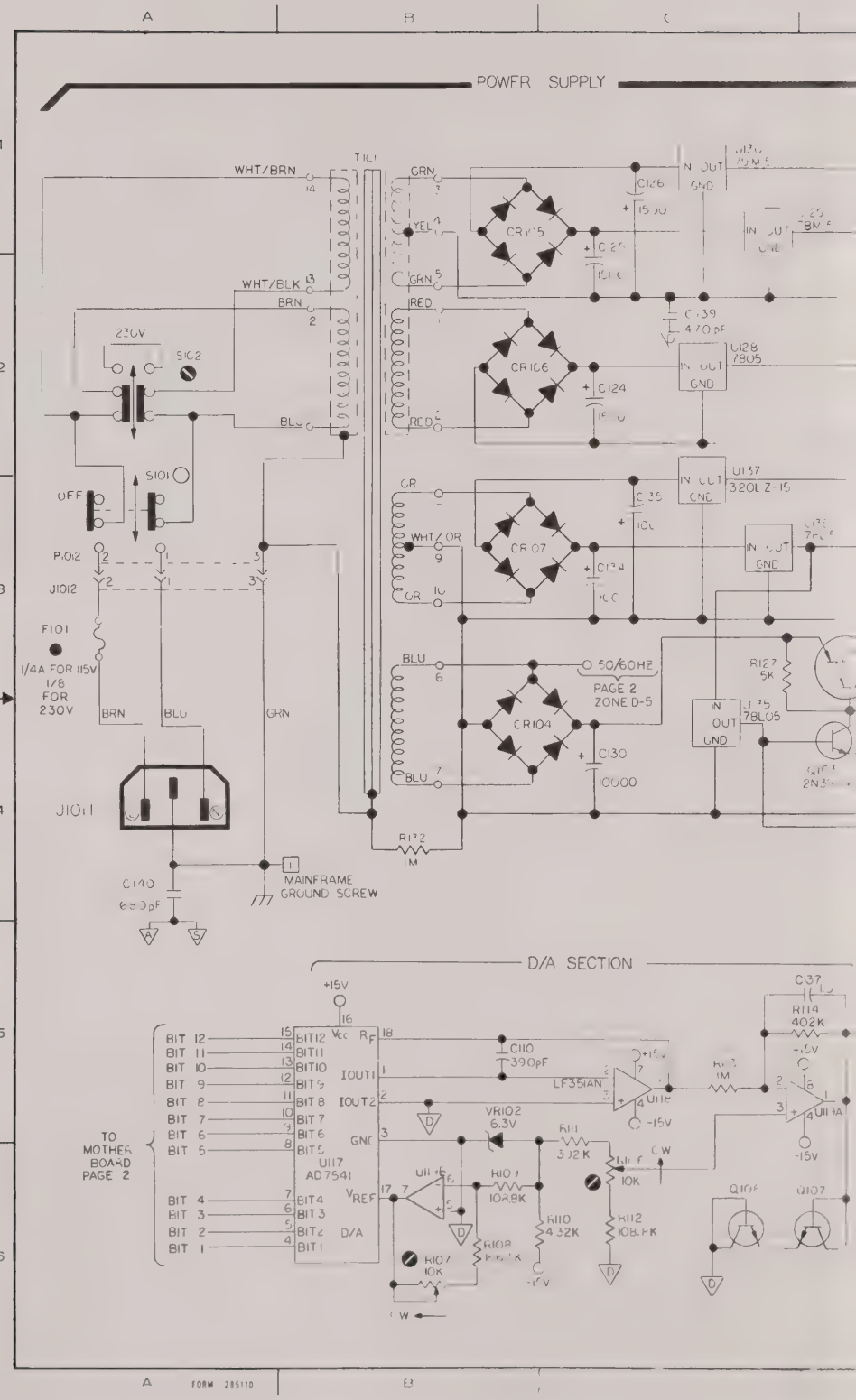
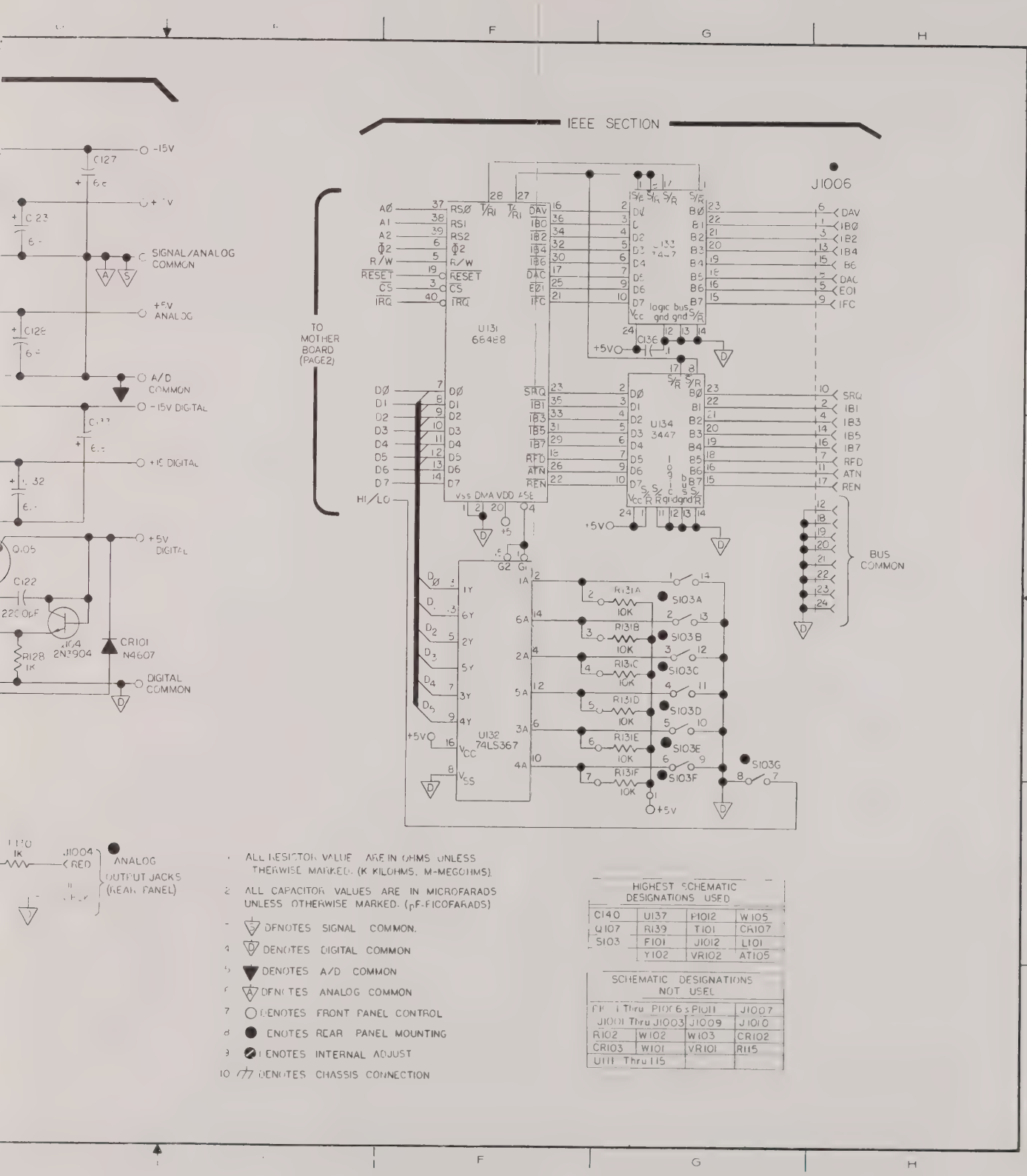


Figure 4-11. Display Board PC-530, Schematic Dwg. No. 30584D


POWER SUPPLY
WHT/BRN
WHT/BLK
BRN
BLU
230V
S102
S101
OFF
P.012
J1012
F101
1/4A FOR 115V
1/8 FOR 230V
BRN
BLU
GRN
J1011
C140
680pF
MAINFRAME GROUND SCREW
GRN
YEL
GRN
RED
RED
CR105
CR106
CR107
CR104
C126
1500
C125
1500
C139
470pF
C124
1500
C135
100
C134
100
C130
10000
WHT/OR
OR
OR
BLU
BLU
50/60HZ
PAGE 2 ZONE D-5
R172
1M
U128
7805
U137
320L Z-15
U135
78L05
R127
5K
IN
OUT
GND
D/A SECTION
+15V
TO MOTHER BOARD PAGE 2
BIT 12
BIT 11
BIT 10
BIT 9
BIT 8
BIT 7
BIT 6
BIT 5
BIT 4
BIT 3
BIT 2
BIT 1
U117
AD7541
IOUT1
IOUT2
GND
VREF
D/A
C110
390pF
LF351AN
U116
-15V
VR102
6.3V
R111
3.32K
R110
4.32K
R112
108.FK
R107
10K
CW
R114
402K
R113
1M
U113A
Q106
Q107



1. ALL RESISTOR VALUES ARE IN OHMS UNLESS OTHERWISE MARKED. (K-KILOHMS, M-MEGOHMS).
2. ALL CAPACITOR VALUES ARE IN MICROFARADS UNLESS OTHERWISE MARKED. (pF-PICOFARADS)
3. DENOTES SIGNAL COMMON.
4. DENOTES DIGITAL COMMON
5. DENOTES A/D COMMON
6. DENOTES ANALOG COMMON
7. DENOTES FRONT PANEL CONTROL
8. DENOTES REAR PANEL MOUNTING
9. DENOTES INTERNAL ADJUST
10. DENOTES CHASSIS CONNECTION

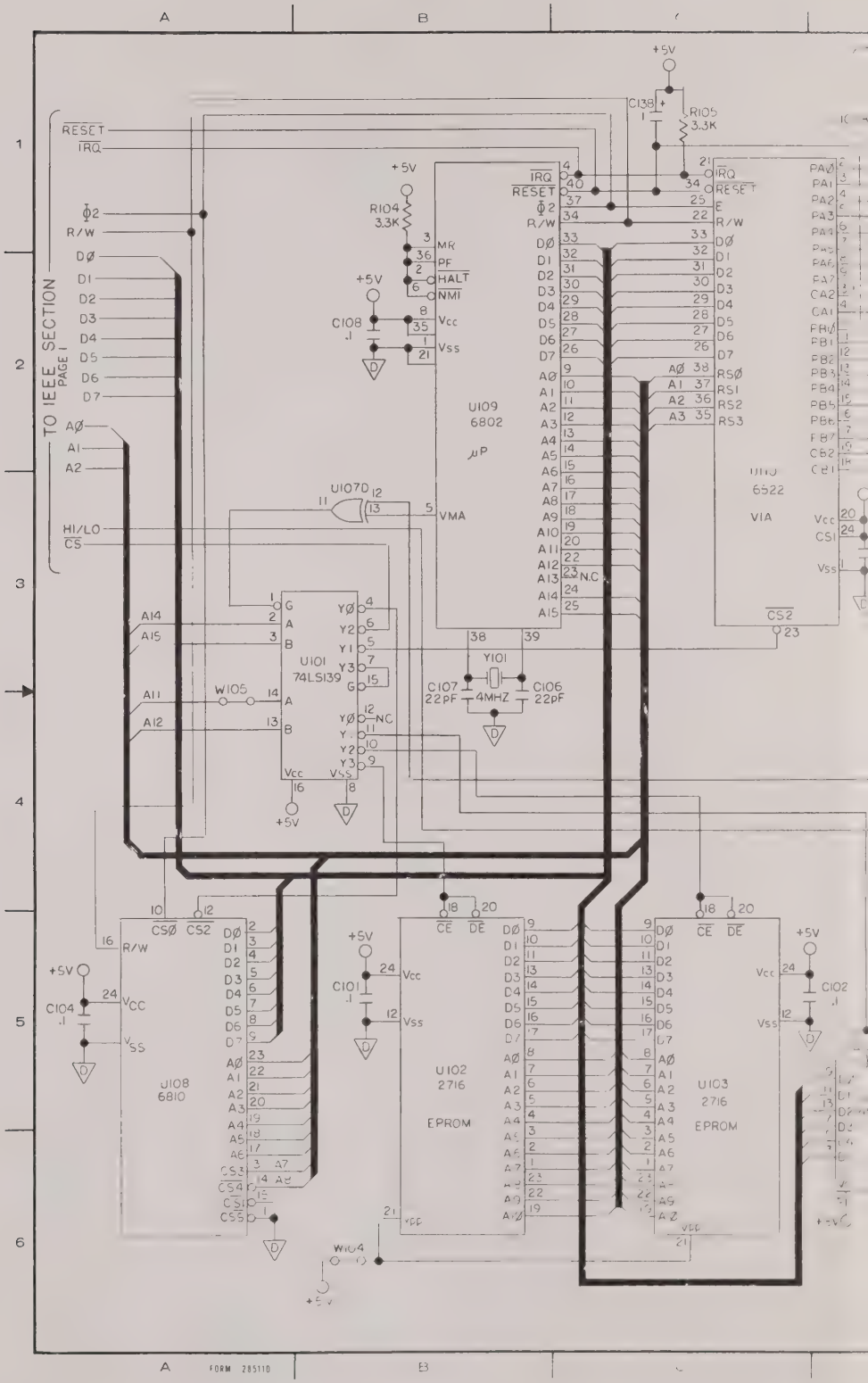
HIGHEST SCHEMATIC DESIGNATIONS USED

C140	U137	P1012	W105
Q107	R139	T101	CR107
S103	F101	J1012	L101
	Y102	VR102	AT105

SCHEMATIC DESIGNATIONS NOT USED

P1 Thru P106 & P1011			J1007
J1001 Thru J1003		J1009	J1010
R102	W102	W103	CR102
CR103	W101	VR101	R115
U111 Thru 115			

Figure 4-12. Digital Board PC-531, Schematic Diagram, Dwg. No. 30583D (sheet 1 of 2)


TO IEEE SECTION PAGE 1
RESET
IRQ
Φ2
R/W
D0
D1
D2
D3
D4
D5
D6
D7
A0
A1
A2
HI/LO
CS
+5V
R105 3.3K
C138
R104 3.3K
MR
PF
HALT
NMI
Vcc
Vss
C108 .1
U109 6802 μP
U107D
VMA
N.C.
U101 74LS139
W105
A14
A15
A11
A12
Y101
C107 22PF
4MHZ
C106 22PF
U110 6522 VIA
RS0
RS1
RS2
RS3
CS2
U108 6810
CS0
CS1
CS3
CS4
CS5
U102 2716 EPROM
U103 2716 EPROM
CE
OE
C104 .1
C101 .1
C102 .1
W104
A
B
C
D
FORM 28511D

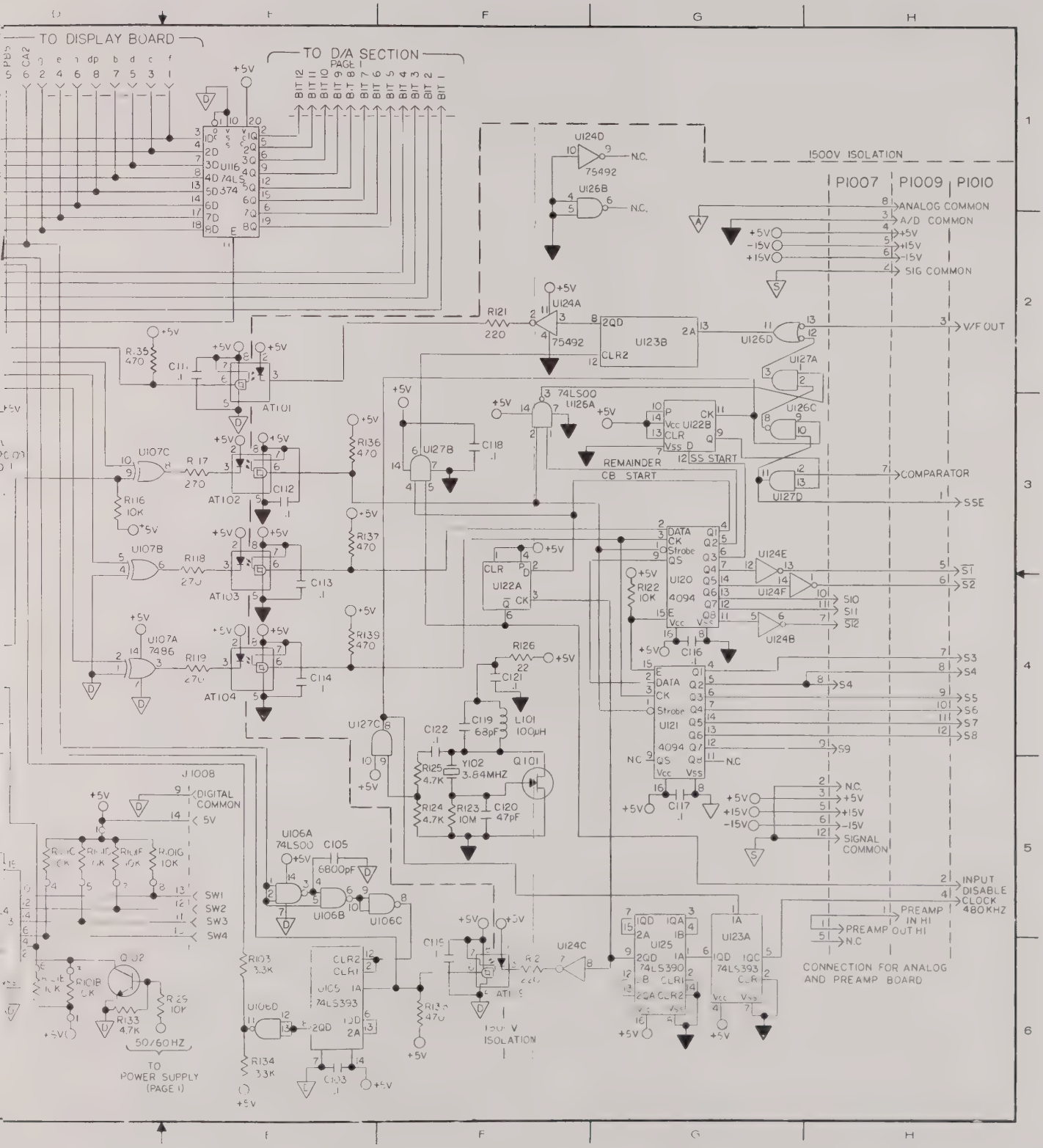


Figure 4-12. Digital Board PC-531, Schematic Diagram, Dwg. No. 30583D (sheet 2 of 2)

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SERVICE FORM

Model No. _____ **Serial No.** _____ **P.O. No.** _____ **Date** _____

Name _____ **Phone** _____

Company _____

Address _____

City _____ **State** _____ **Zip** _____

List all control settings and describe problem. _____

_____

_____

_____ (Attach additional sheets as necessary.)

Show a block diagram of your measurement system including all instruments connected (whether power is turned on or not). Also describe signal source.

Where is the measurement being performed? (factory, controlled laboratory, out-of-doors, etc.) _____

What power line voltage is used? _____ Variation? _____

Frequency? _____ Ambient Temperature? _____ °F.

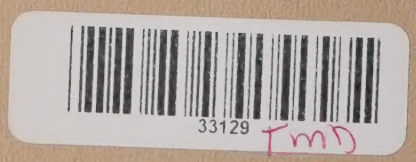
Variation? _____ °F. Rel. Humidity? _____ Other? _____

Any additional information. (If special modifications have been made by the user, please describe below.)

_____

_____

*Be sure to include your name and phone number on this service form.



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